

Min-Bias Models The Modeling of ND, SD, DD

Peter Skands (CERN PH-TH)

Disclaimer

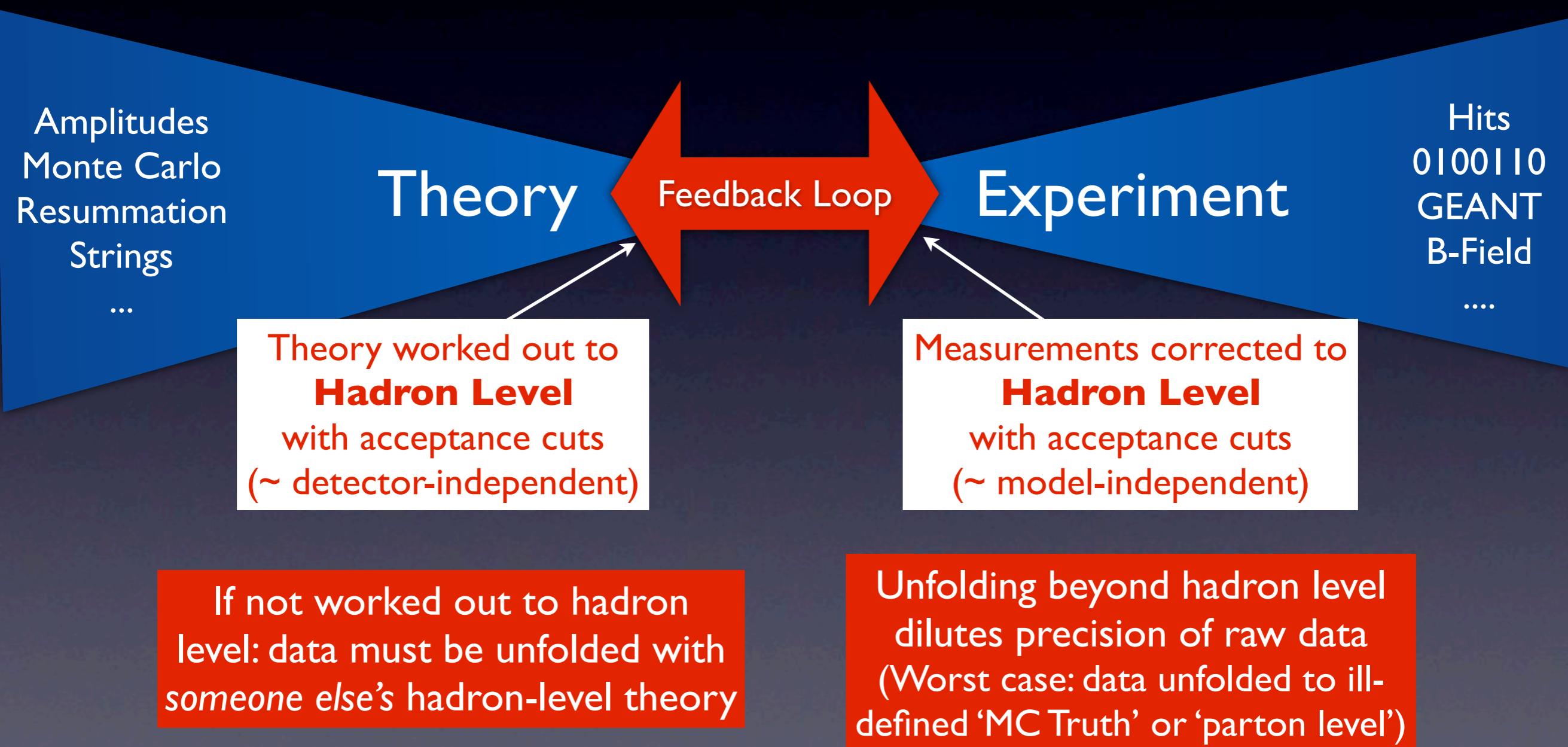
- Not giving this talk to explain diffraction models, but to give input from modeling community
- **Focus on important** outstanding questions *addressed by early LHC data*
- **The answers are** crucial to *improving* our physics models

Monte Carlos and Precision

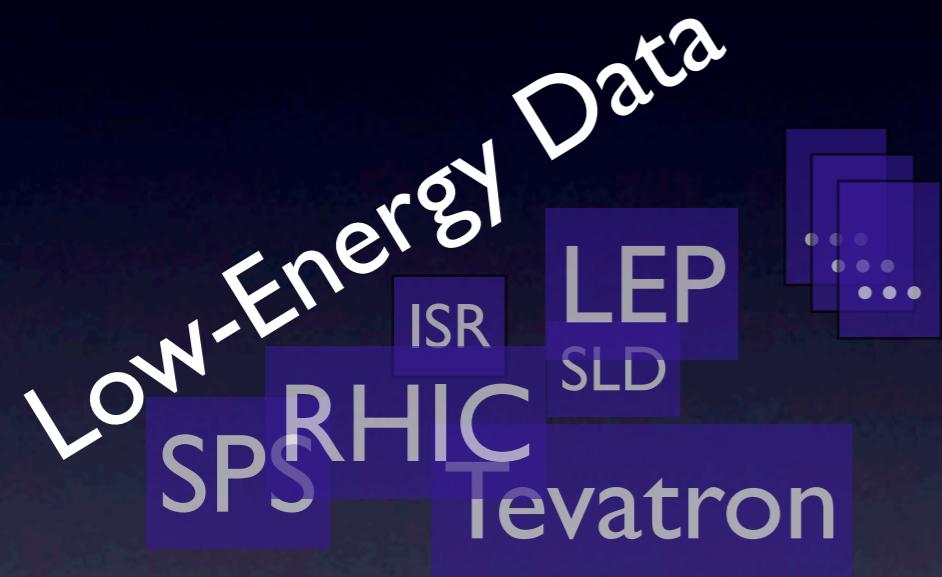
- **A Good Physics Model** gives you
 - **Reliable calibrations** for both signal and background (e.g., jet energy scales)
 - **Reliable corrections** (e.g., track finding efficiencies)
 - **Background estimates** with as small uncertainty as possible (fct of both theoretical accuracy and available experimental constraints)
 - **Reliable discriminators** with maximal sensitivity to New Physics

Count what is Countable
Measure what is Measurable
(and keep working on the beam)

G. Galilei

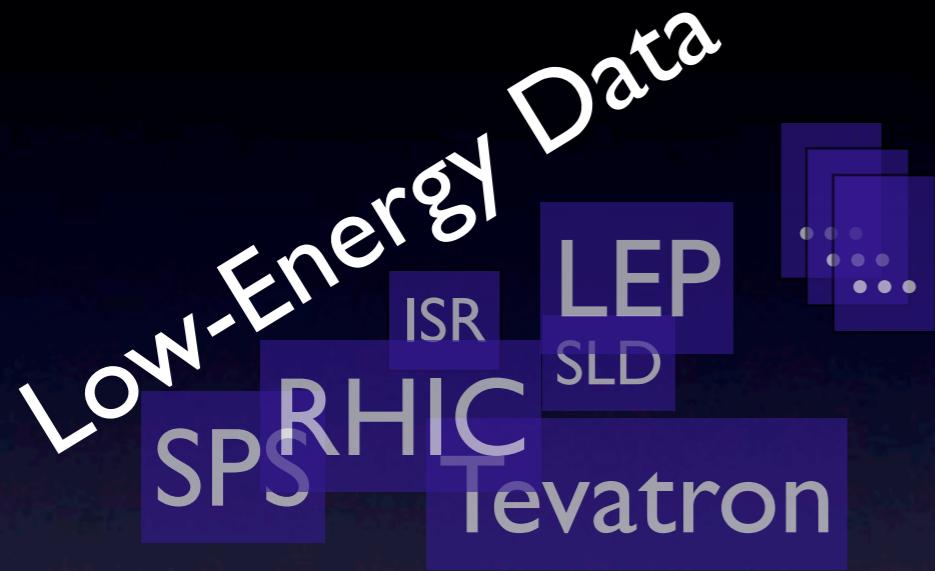


Constraining Models



- A wealth of data available at lower energies
- Used for constraining ('tuning') theoretical models (E.g., Monte Carlo Event Generators)

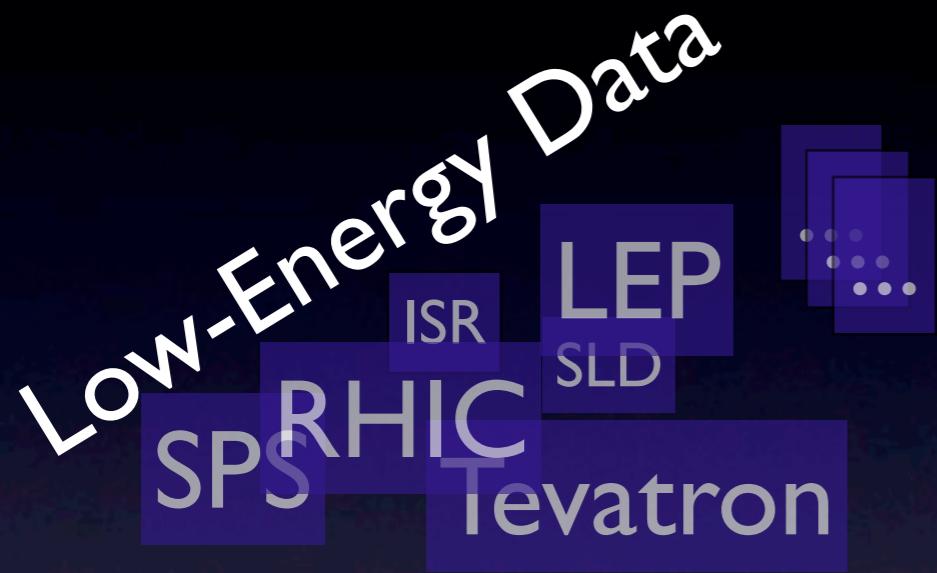
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- Which model would you trust more? One that also describes SPS, RHIC, Tevatron, Low-Energy LHC? Or one that doesn't?

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But wait ... which gaps?

Charged Multiplicity

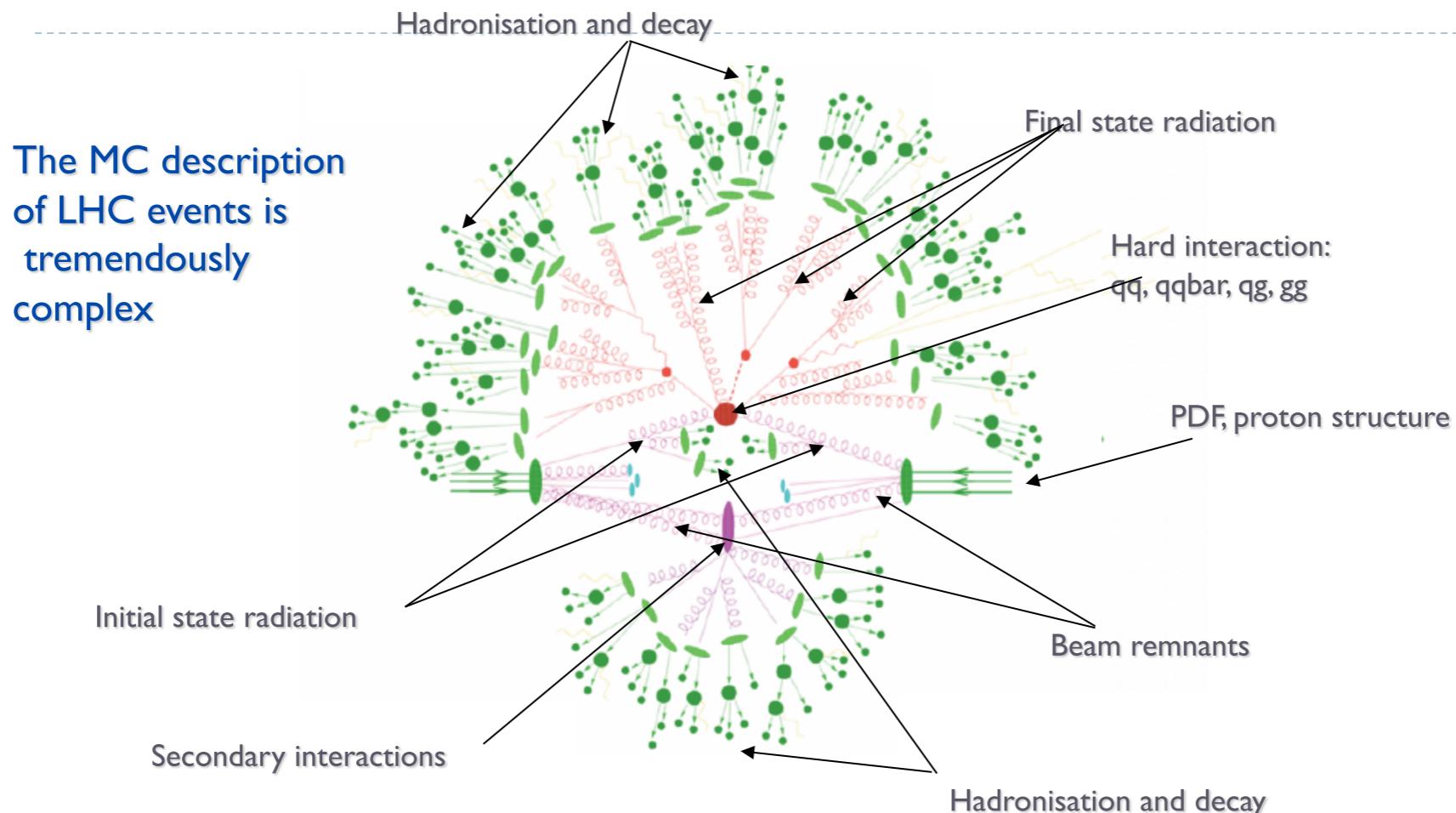
- One of the most fundamental quantities to measure
 - But fundamental does not imply easy

Charged Multiplicity

- One of the most fundamental quantities to measure
 - But fundamental does not imply easy
 - Complications: Corrections for Trigger Bias, Diffraction, Zero Bin, Long-Lived particles, Extrapolations from raw measurement to: hadron-level (with acceptance cuts) and/or to: hadron-level (full phase space), ...

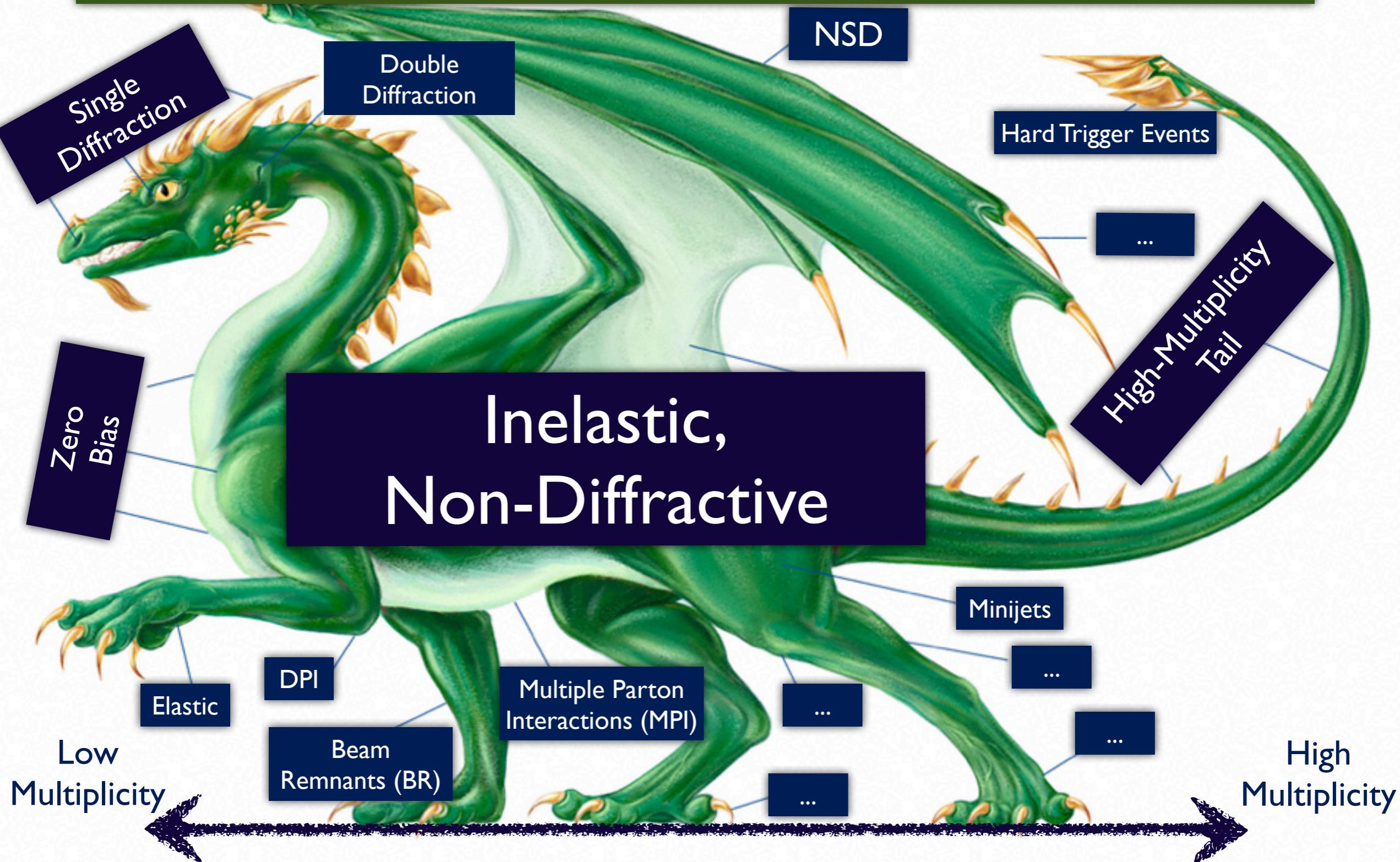
Dissecting Minimum-Bias

Physics requirements: basics



This is a schematization to be able to cut down the problem in pieces and model them in a different way. The “pieces” are correlated !

Dissecting Minimum-Bias



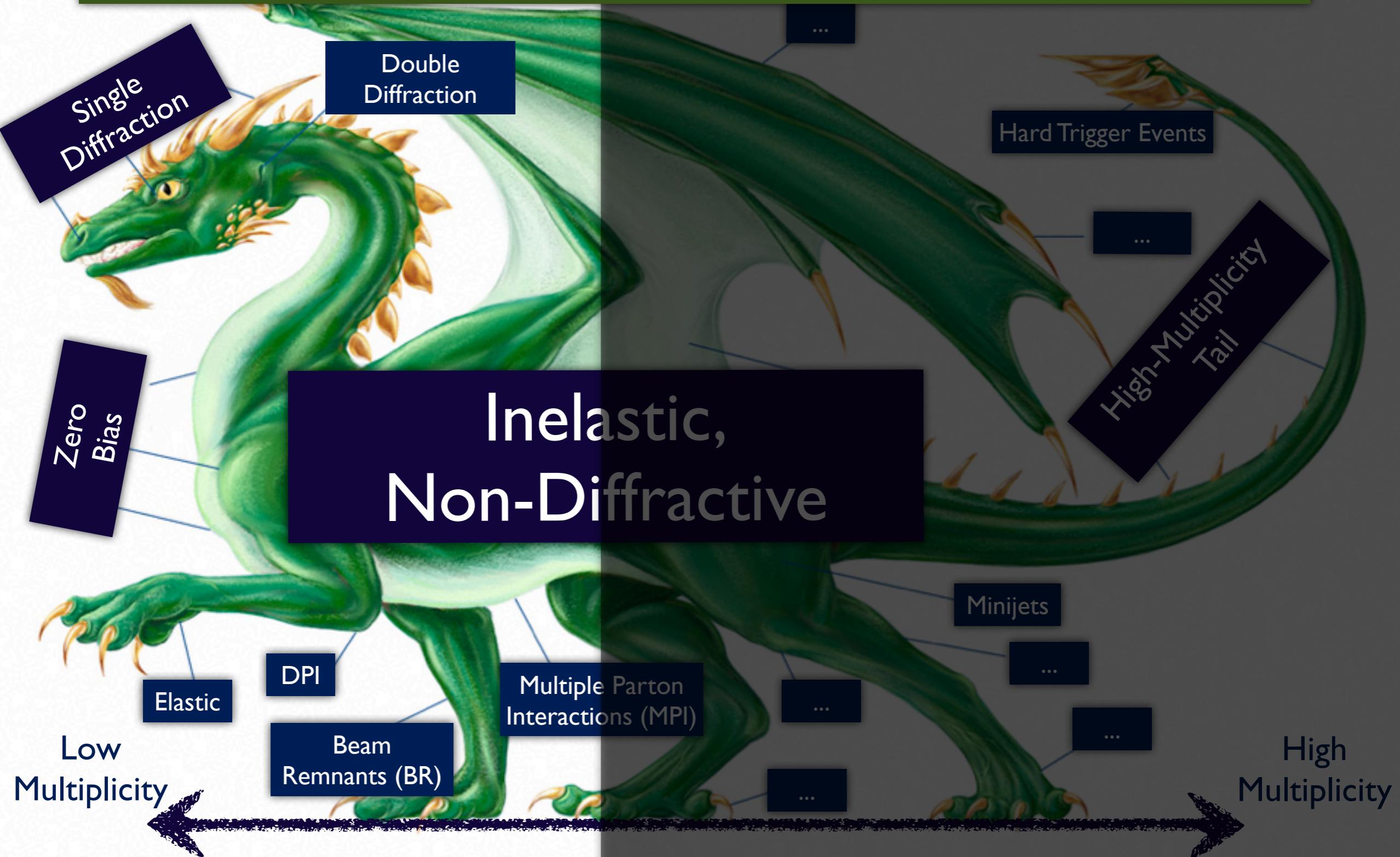
Measured Results

- How to Compare to Older Measurements?
 - Bubble chambers etc extrapolated to full phase space
 - More model-dependent at Tevatron and LHC experiments

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- How to Compare to Older Measurements?
 - Bubble chambers etc extrapolated to full phase space
 - More model-dependent at Tevatron and LHC experiments
- How to Compare to Theory?
 - Inelastic > ‘NSD’ > Inelastic Non-Diffractive, ... ?
 - For all: Define event set in terms of hadron-level cuts (model-*inspired*, yes, but not model-*dependent*)
 - Model constraints not helped by filling up unmeasured region with some model/fit (especially if it is some other guy’s model) - Keep main measured result as close to raw acceptance as possible.
Extrapolate *only* to do comparisons (inflates uncertainties)

Issues at Low Multiplicity



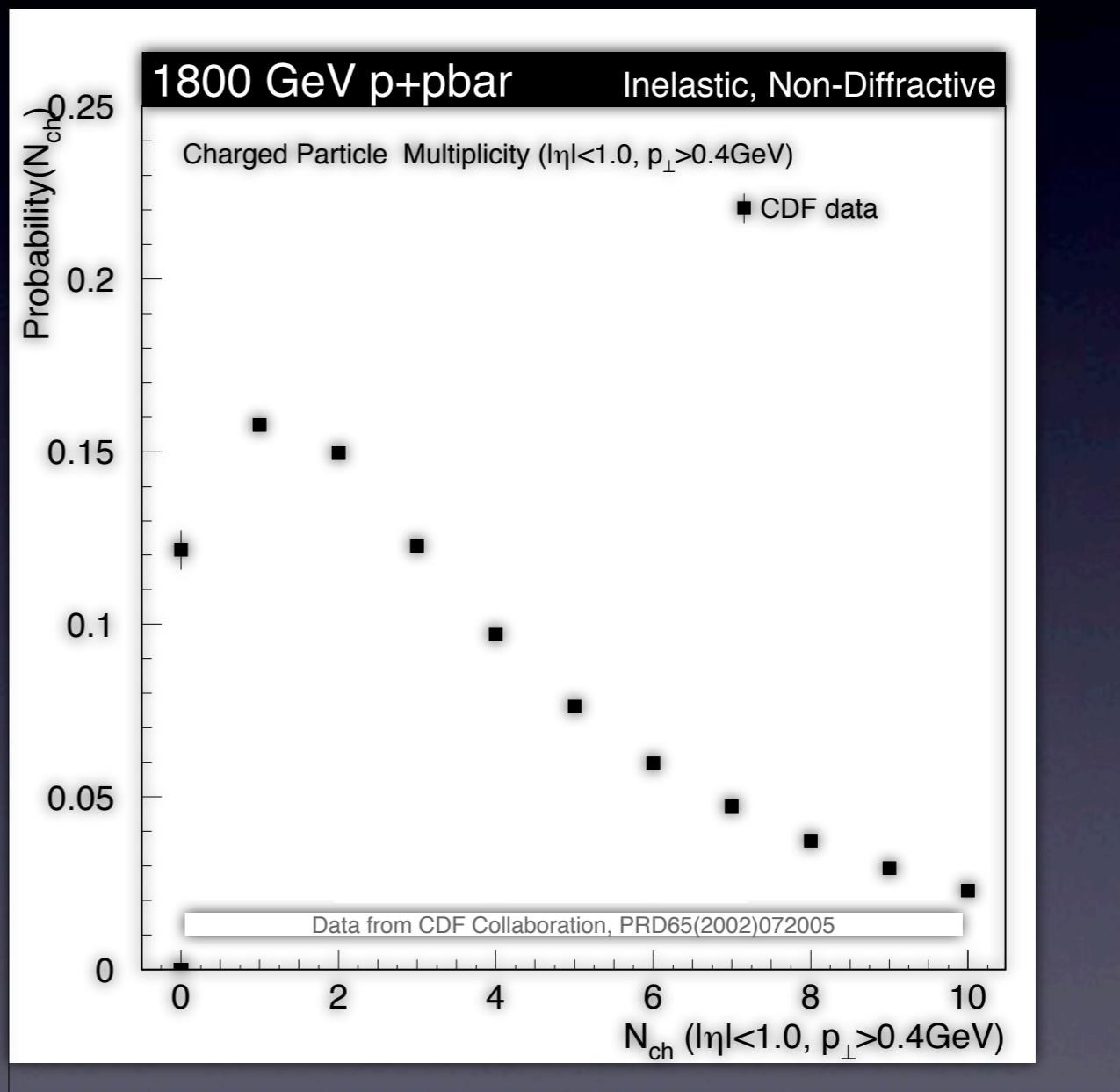
Low Multiplicities: Correcting for Diffraction

- Diffractive processes
 - Large part of total cross section
 - Populate the low-multiplicity bins: lower $\langle N_{ch} \rangle$
 - Characteristic rapidity spectrum with large rapidity gaps: affect $dN_{ch}/d\eta$
 - Impossible to interpret min-bias spectra without knowing precisely how diffraction was treated

cf. Beate's talk

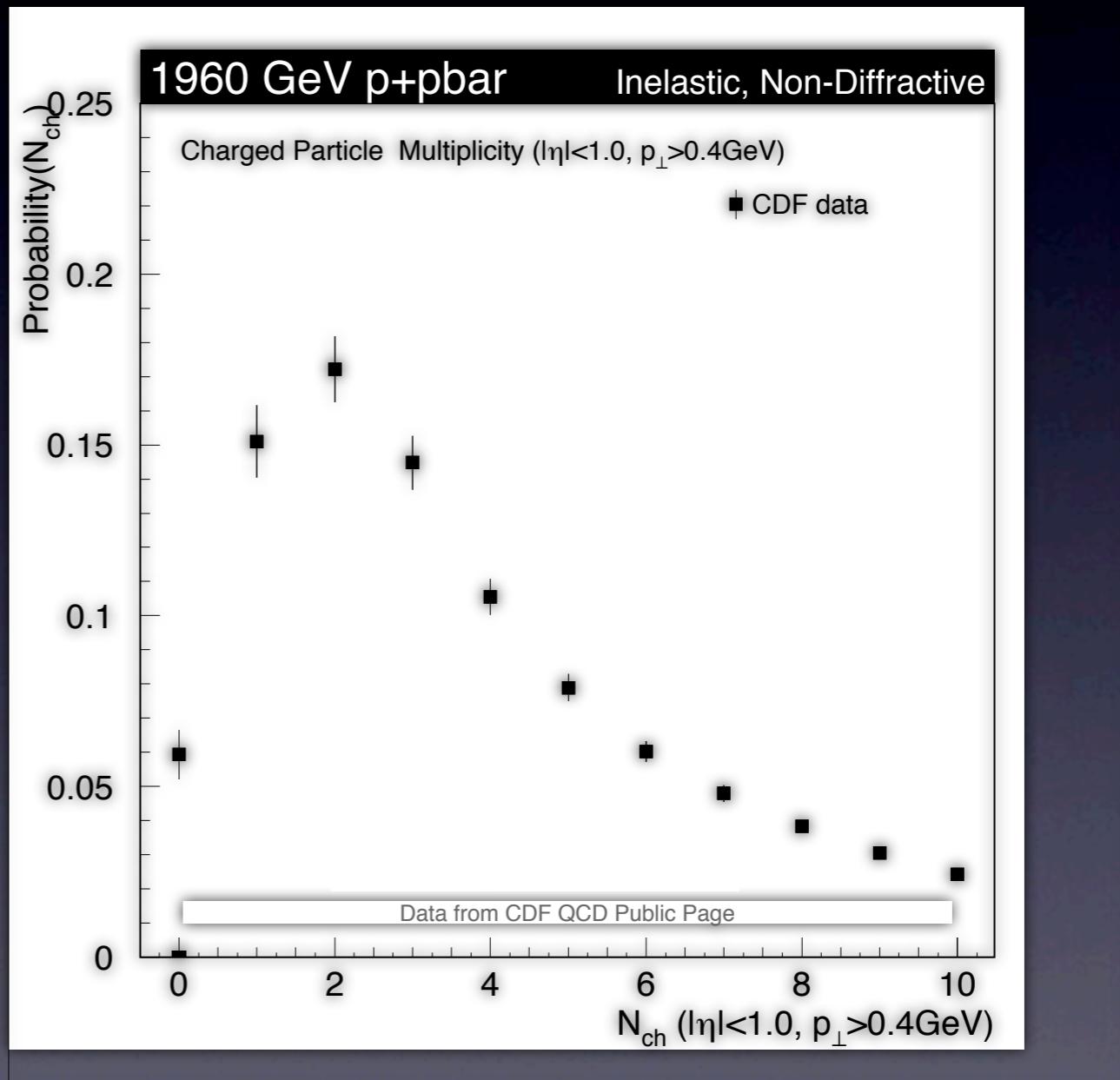
Low Multiplicities: Correcting for Diffraction

- CDF Run-I Data
 - Corrected to $pT > 0.4 \text{ GeV}$ instead of full PS: less model dependence
 - First few bins corrected for diffraction (also affects average N_{ch} and $dN/d\eta$)



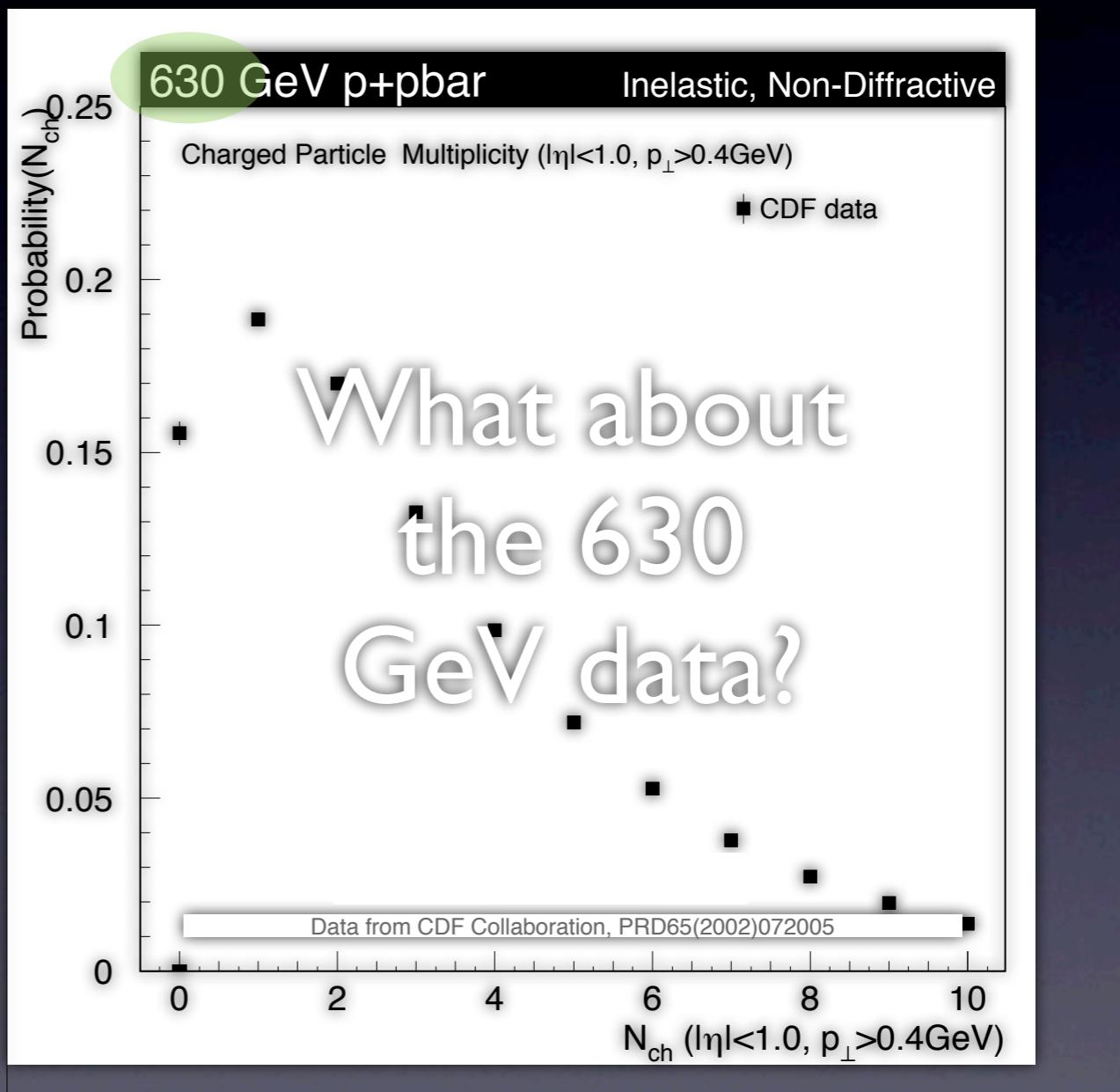
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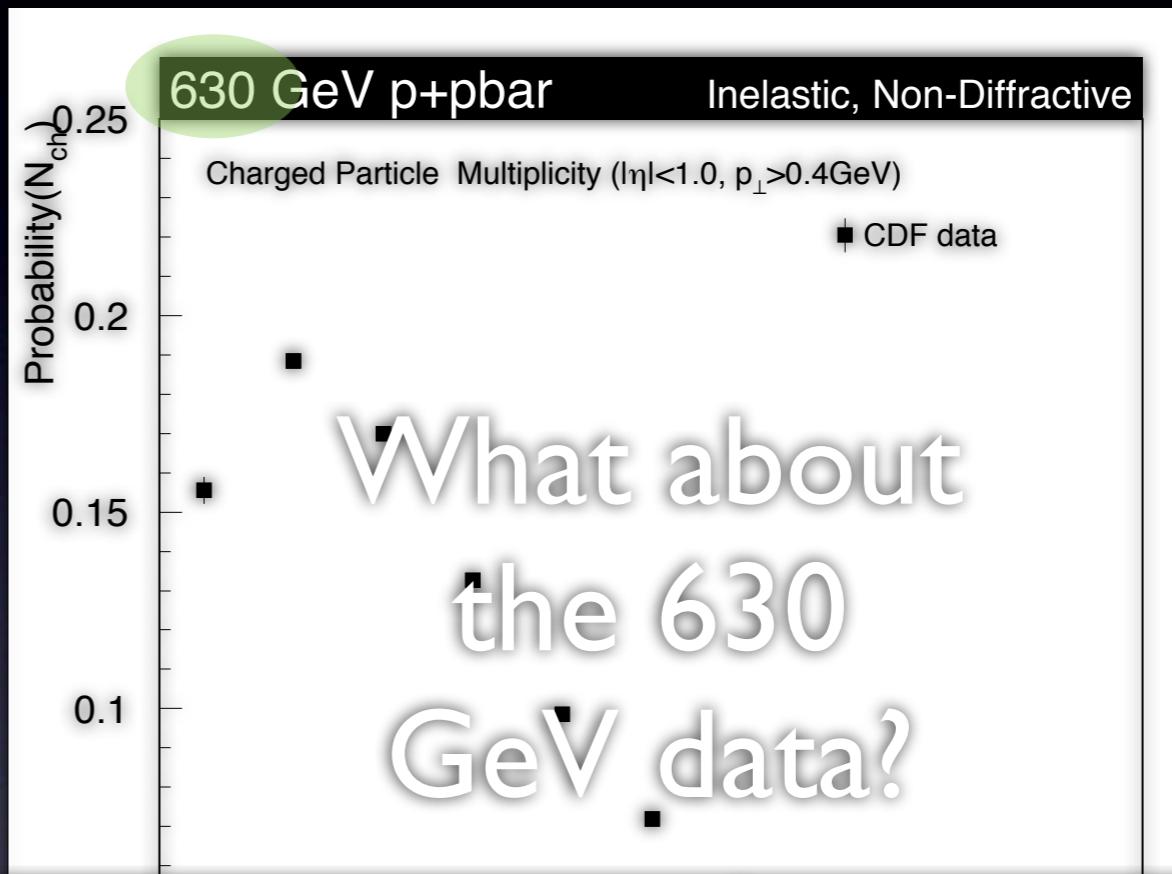
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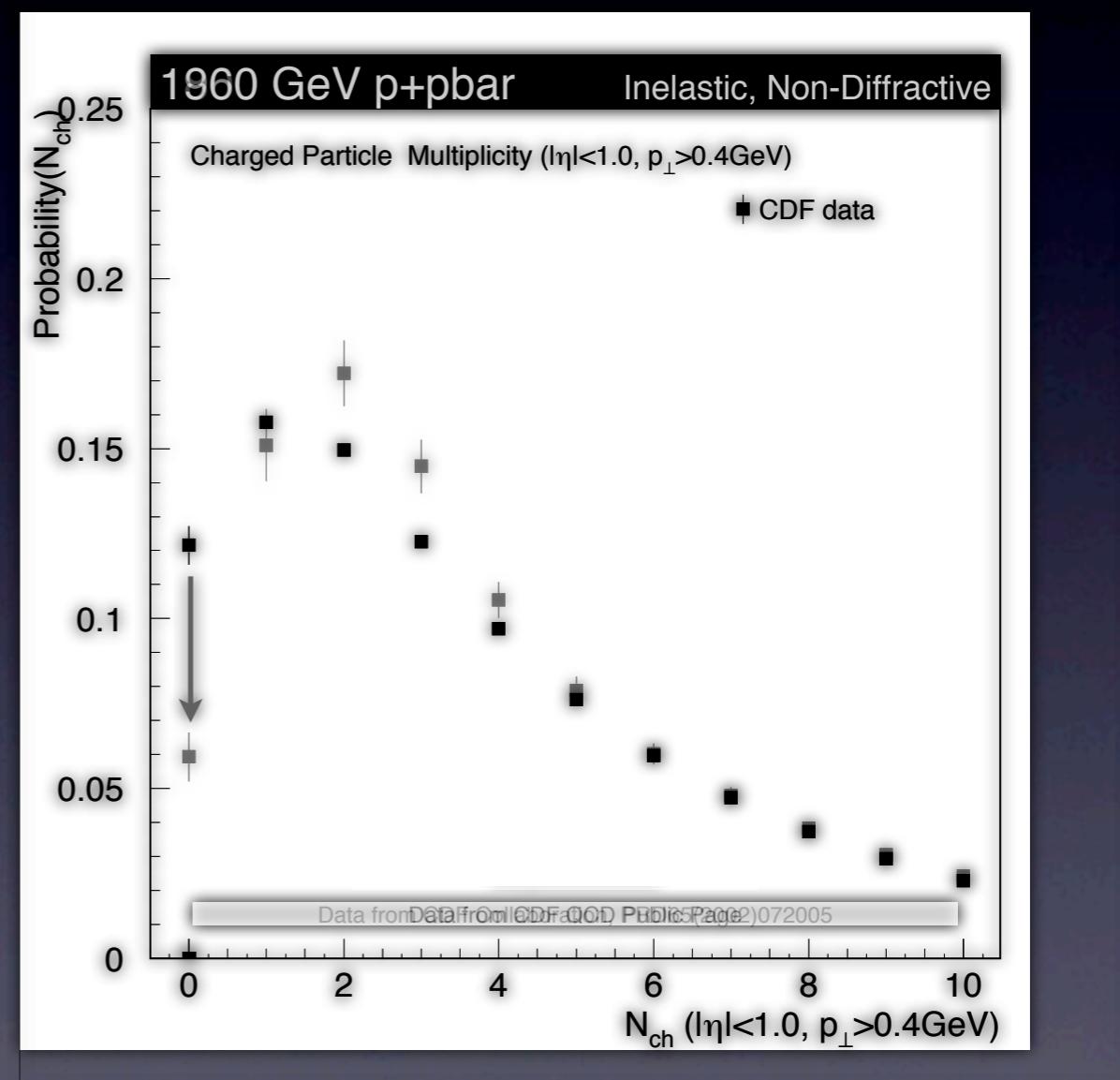
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 - First few bins



LHC Measurements at 900 and 2360 GeV, with a well-defined, agreed-upon, definition of diffraction can kill this issue

The Zero Bin

- The most problematic is the **zero bin**: *the event was triggered, but no fiducial tracks*
 - *E.g, was it a diffractive event with no tracks, or an inelastic non-diffractive event, with no tracks? Or ...?*



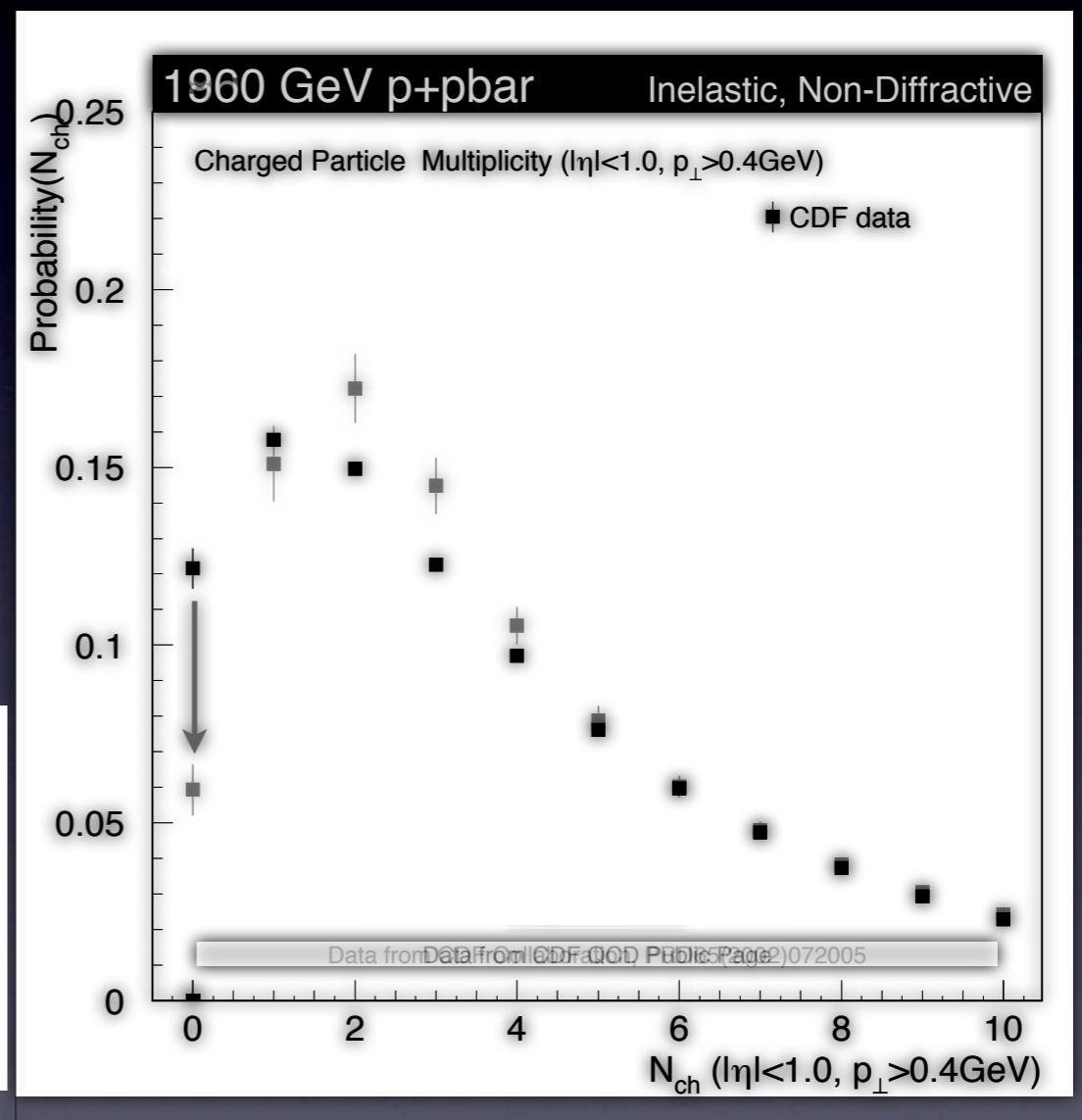
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Predictions for Mean Densities of Charged Tracks

	$\frac{\langle N_{\text{ch}} \rangle _{N_{\text{ch}} \geq 0}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{\text{ch}} \rangle _{N_{\text{ch}} \geq 1}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{\text{ch}} \rangle _{N_{\text{ch}} \geq 2}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{\text{ch}} \rangle _{N_{\text{ch}} \geq 3}}{\Delta\eta\Delta\phi}$
LHC 10 TeV	0.40 ± 0.05	0.41 ± 0.05	0.43 ± 0.05	0.46 ± 0.06
LHC 14 TeV	0.44 ± 0.05	0.45 ± 0.06	0.47 ± 0.06	0.51 ± 0.06

PS, Perugia Proceedings, arXiv:0905.3418 [hep-ph]



Redefine the event sample to include at least one fiducial track?

→ATLAS

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A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

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CMS Collaboration, JHEP 02 (2010) 041



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However, it lacks a clear definition at the particle level

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I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)	eta gap
1	p+	0.38955	-0.09031	-444.18188	← 444.18305	0.93827	
2	p+	0.55491	-0.32947	118.14484	118.15033	0.93827	
3	pi+	-0.10520	0.04623	21.97324	21.97398	0.13957	
4	pi-	-0.36420	0.20220	79.60000	79.60121	0.13957	
5	pi+	0.18465	-0.31136	44.33333	44.33503	0.13957	
6	pi-	-0.65347	0.35445	10.76828	10.79481	0.13957	
7	pi+	-0.31719	-0.18864	4.89293	4.90881	0.13957	
8	pi-	0.18684	-0.24438	0.75472	0.82687	0.13957	
9	pi+	0.01778	0.47298	1.28424	1.37578	0.13957	
10	pi-	0.28540	-0.36795	2.98245	3.02181	0.13957	
11	K+	0.01880	0.15742	2.95334	2.99849	0.49360	
12	pi-	0.07232	0.23225	6.16625	6.17263	0.13957	
13	pi+	-0.37412	0.04117	0.68340	0.79257	0.13957	
14	pi-	0.12547	0.33701	2.03239	2.06867	0.13957	
15	pi+	0.03865	0.05823	0.98258	0.99490	0.13957	
16	pi-	0.16134	0.03535	4.09086	4.09657	0.13957	
17	pi-	-0.06906	0.08845	1.96279	1.97095	0.13957	
18	pi+	0.11852	-0.32616	3.70555	3.72438	0.13957	
sum(p). mass:		0.27097	0.16745	-136.87069	751.99084	739.42987	

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MC “Truth”: Double Diffractive

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14	pi-						7
15	pi+						7
16	pi-						7
17	pi-						7
18	pi+						7
	sum(p). ma						

MC “Truth”: Double Diffractive

Minimal Conclusion: gap definition
not foolproof if we see charged only

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.18101	-0.23124	427.60408	427.60521	0.93827
2	p+	-0.06244	-0.10079	-231.29111	231.29304	0.93827
3	K+	0.33646	0.18878	-33.91055	33.91634	0.49360
4	nbar0	0.54816	-0.06834	-1.20905	1.62781	0.93957
5	pi0	-0.37380	0.02504	0.35486	0.53338	0.13498
6	n0	-0.08115	-0.02823	-0.53314	1.08370	0.93957
7	pi-	-0.23393	0.11296	-5.76403	5.77157	0.13957
8	K-	-0.00627	-0.15812	-44.71705	44.72006	0.49360
9	K+	-0.03848	-0.01139	-64.08264	64.08456	0.49360
10	pi-	-0.02479	0.08067	-2.09126	2.09761	0.13957
11	pi+	-0.41465	-0.13479	-8.29972	8.31234	0.13957
12	pi0	-0.50854	0.11826	-18.60847	18.61629	0.13498
13	pi-	-0.04847	0.20076	-3.15301	3.16285	0.13957
14	pi0	0.76201	-0.09810	-3.33633	3.42631	0.13498
15	K-	-0.08212	0.24522	0.71152	0.90376	0.49360
16	pi+	0.09763	-0.21837	0.15468	0.31721	0.13957
17	pi+	-0.14039	0.17750	0.46433	0.53507	0.13957
18	pi0	0.23292	-0.41112	2.88185	2.92345	0.13498
19	pi+	-0.17876	-0.03157	6.10565	6.10994	0.13957
20	pi-	0.03074	0.07151	0.33071	0.36729	0.13957
21	pi0	0.06314	-0.09334	0.80407	0.82307	0.13498
22	pi0	-0.16321	-0.13453	0.64843	0.69528	0.13498
23	pi0	-0.14686	-0.00214	0.56642	0.60052	0.13498
24	pi-	-0.01222	-0.27842	0.19750	0.36899	0.13957
25	K_L0	-0.45356	0.56332	4.42730	4.51350	0.49767
26	pi+	-0.17413	-0.00385	-0.03275	0.22559	0.13957
27	pi0	0.21046	-0.04576	-1.03674	1.06744	0.13498
28	pi-	0.04562	-0.11103	1.10752	1.12271	0.13957
29	pi+	-0.15254	0.27925	1.58019	1.61794	0.13957
30	pi+	0.00633	0.23779	-20.99897	21.00078	0.13957
31	pi-	0.09527	-0.14227	-9.49998	9.50254	0.13957
32	pi-	0.39307	0.13431	0.53495	0.69152	0.13957
33	pi+	0.29351	-0.13195	0.09074	0.36231	0.13957
	sum momentum	0.00000	0.00000	0.00000	900.00000	900.00000

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Moral: What some theorist/model defines as SD, DD, etc, *is not itself a physical observable!*

Tails of one are *indistinguishable* from the other
(even with a perfect detector with full PID)

If no physical measurement can tell the difference,
it does not make sense to correct back to

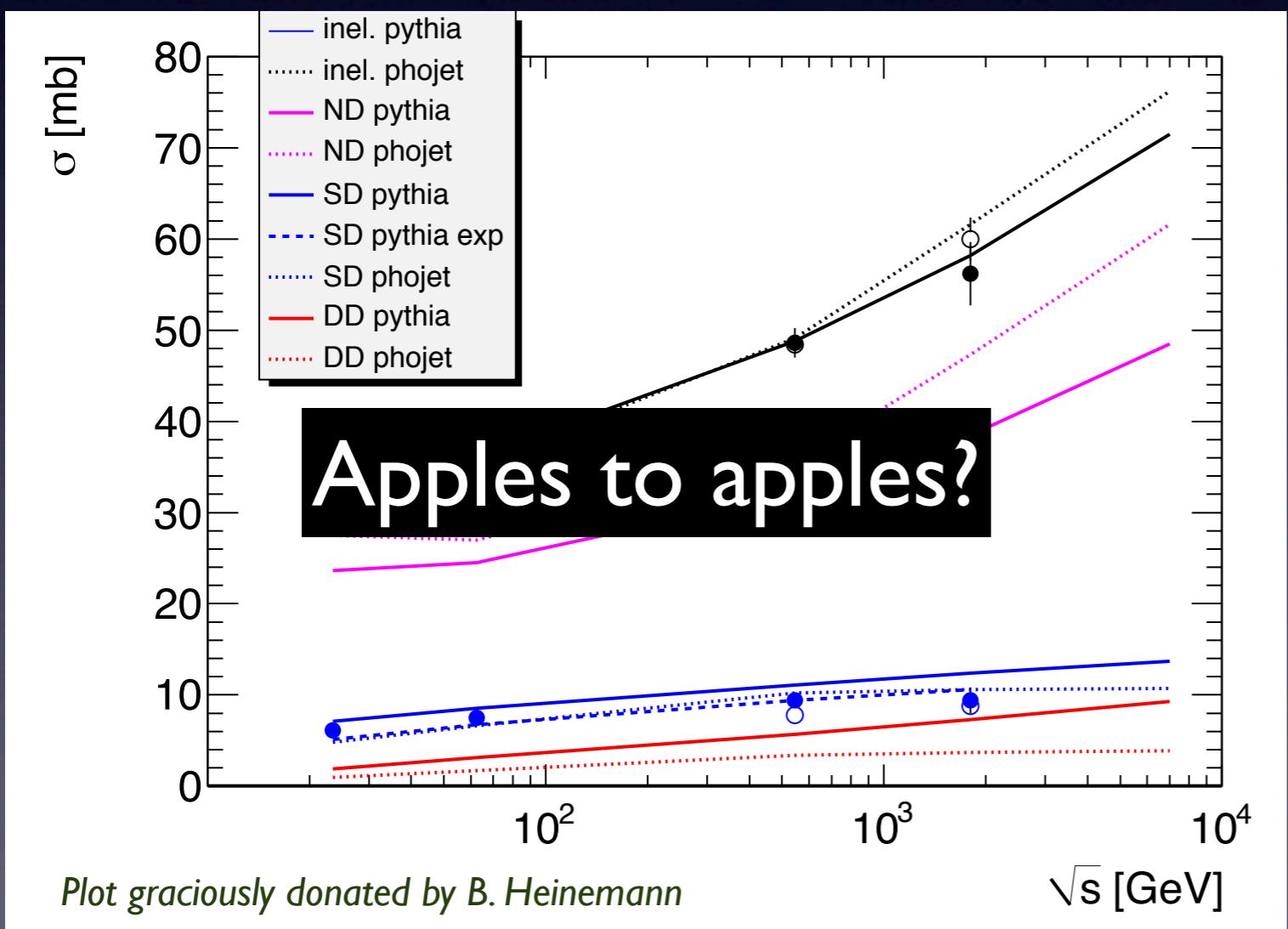
25 K 10 -0.45356 0.56332 4.42730 4.51350 0.49767

And this is even assuming we had the perfect model on which everyone agrees ...

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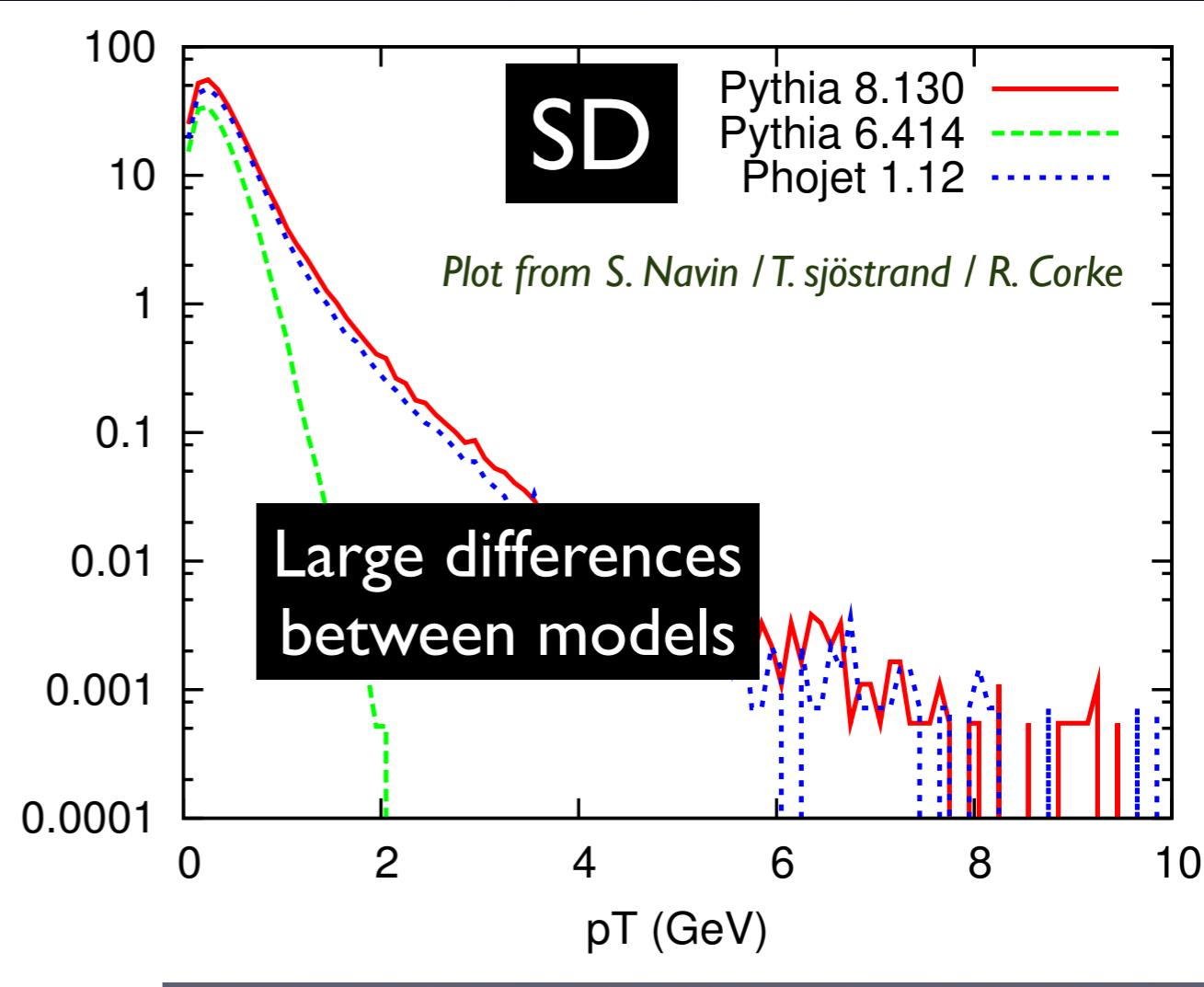
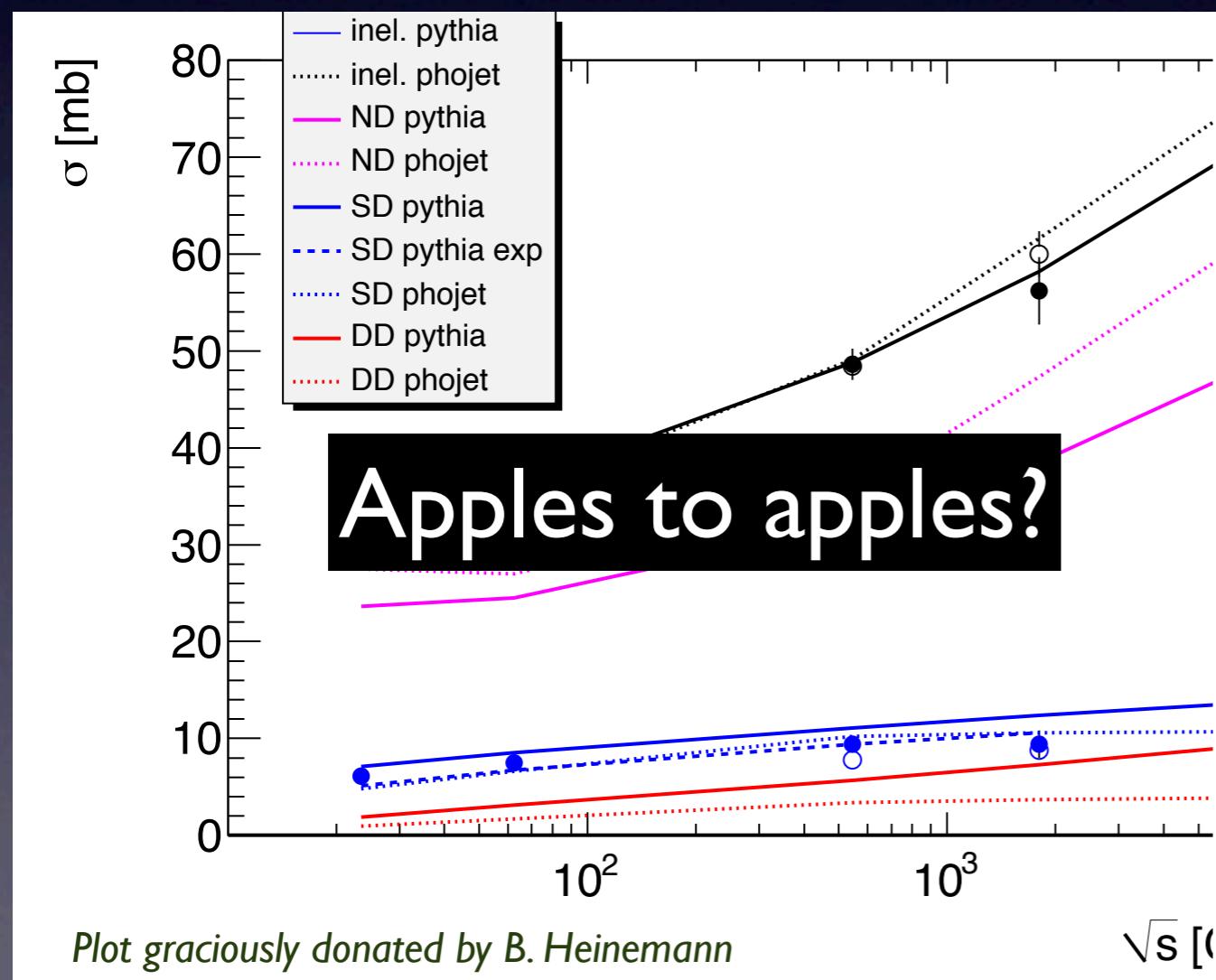
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Traditional, but not optimal

- Defs of SD, DD, ND, etc, are MODEL-DEPENDENT
- Models DO NOT AGREE
- E.g., “NSD” is not a physical definition, unless defined in terms of hadron-level cuts only

Note: diffraction is not, itself, “the evil guy” here. A clear hadron-level definition would also bring diffractive studies on a better, more model-independent, footing.

Ways Out

- A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...
- B) Report a measurement with a given set of hadron-level cuts → MB

Employed in the third LHC paper (?)
ATLAS Collaboration, preliminary
(see talk this morning)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB

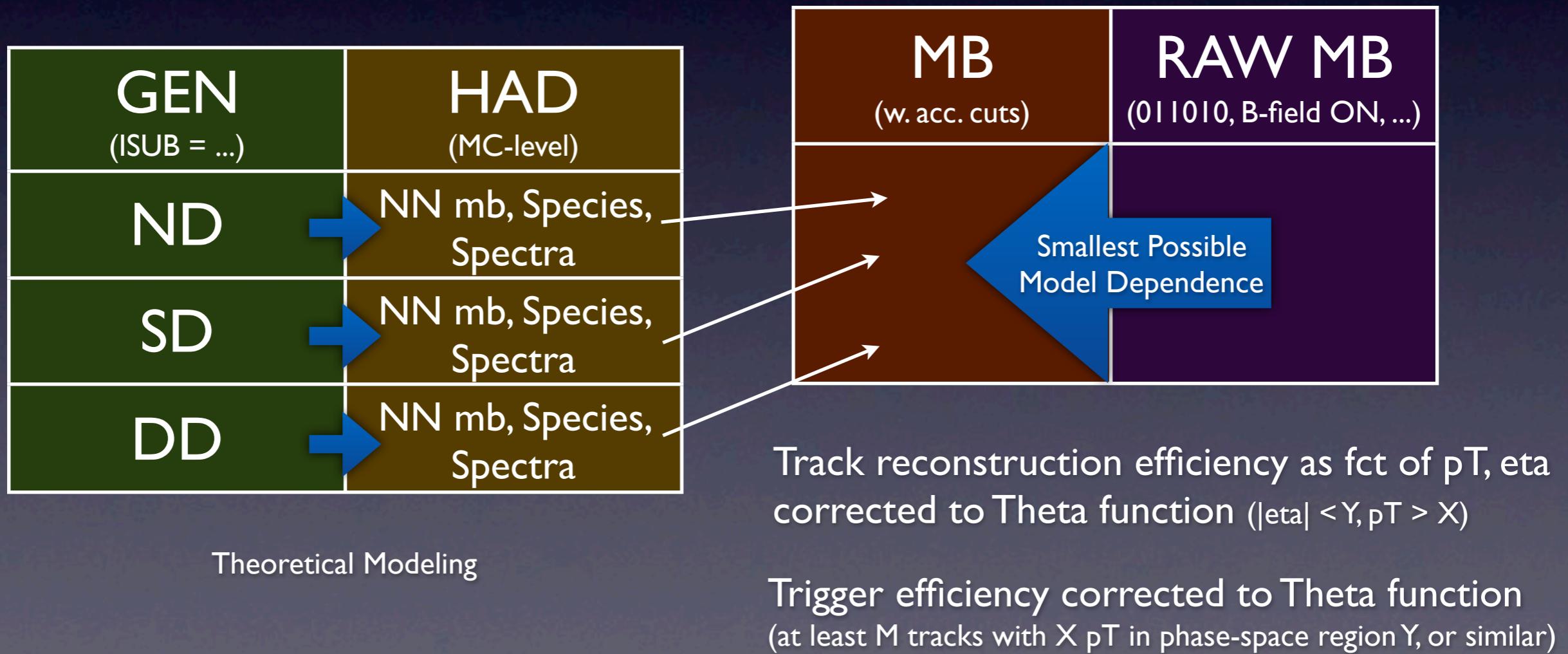
MB (w. acc. cuts)	RAW MB (011010, B-field ON, ...)
	<p>Smallest Possible Model Dependence</p>

Track reconstruction efficiency as fct of pT, eta corrected to Theta function? ($|\eta| < Y, pT > X$)

Trigger efficiency corrected to Theta function?
(at least M tracks with X pT in phase-space region Y, or similar)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB



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Drawbacks?

- “MB” is not “ZB”
- “MB” is acc/trig-dependent mixture of SD, DD, ND
- **How to compare** with other measurements or “GEN”-level theory cross sections (e.g., sigmaDiff)?

MB (w. acc. cuts)	RAW MB (011010, B-field ON, ...)
	<p>Smallest Possible Model Dependence</p>

Track reconstruction efficiency as fct of pT, eta corrected to Theta function ($|\eta| < Y, pT > X$)

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Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB

Drawbacks?

- MB was never ZB (clear & simple event selection criteria = good enough)
- Mixture of SD, DD, ND in given region = **modeling aspect**
 - The most you can do is optimize selection to enhance, e.g., “ND”
- **HAD-level observables** and event-sample definitions give us *not* a ready-made solution but:
 - **A well-defined measurement** and reference for posterity ...
 - **With the smallest** possible uncertainties ...
 - **A base for** comparisons to other definitions (other exps / TH defs)

Ways Out

C) More information? Partition MB sample into various “enriched” samples?

Systematically introduce “biases”



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Systematically introduce “biases”



- SD-Enriched HAD-level sample (*cannot be 100% Use models to estimate best purity*)
More sensitive to SD cross section. Report observed cross section,
then translate to SD-GEN-level cross section using best models of the day.
(Don't just tell us the latter.)
- ND-Enriched HAD-level sample (can be almost 100%)
 - ...
 - ...

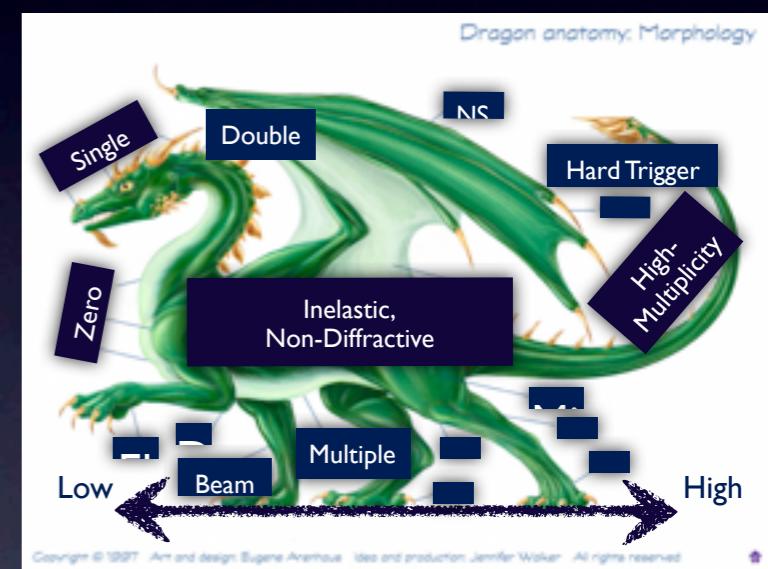
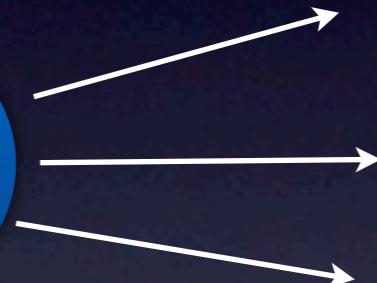
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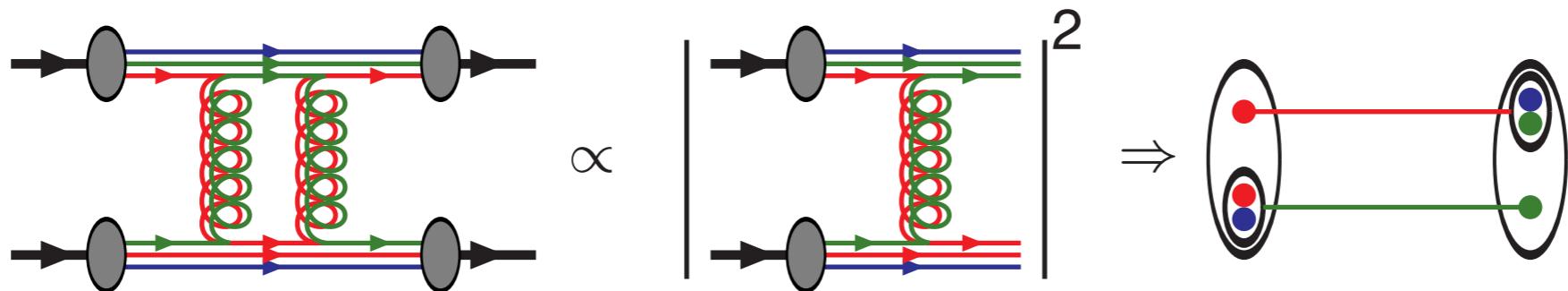
Modeling Diffraction

- PYTHIA 6
- POMPYT, POMWIG
- PHOJET (& Relatives)
- PYTHIA 8
- HERWIG++
- SHERPA
- EPOS, RAPGAP, ...

PHOJET (& Relatives)

(1) Cut Pomeron (1982)

- Pomeron predates QCD; nowadays \sim glueball tower
- Optical theorem relates σ_{total} and σ_{elastic}



- Unified framework of nondiffractive and diffractive interactions
- Purely low- p_{\perp} : only primordial k_{\perp} fluctuations
- Usually simple Gaussian matter distribution

(2) Extension to large p_{\perp} (1990)

- distinguish soft and hard Pomerons (cf. Ivan):
 - soft = nonperturbative, low- p_{\perp} , as above
 - hard = perturbative, “high”- p_{\perp}
- hard based on PYTHIA code, with lower cutoff in p_{\perp}

Slide from T. Sjostrand

Status: PHOJET web site back up as of Sunday (?)

PYTHIA 6

Diffractive Cross Section Formulae:

$$\frac{d\sigma_{sd(AX)}(s)}{dt dM^2} = \frac{g_{3IP}}{16\pi} \beta_{AIP}^2 \beta_{BIP} \frac{1}{M^2} \exp(B_{sd(AX)}t) F_{sd},$$

$$\frac{d\sigma_{dd}(s)}{dt dM_1^2 dM_2^2} = \frac{g_{3IP}^2}{16\pi} \beta_{AIP} \beta_{BIP} \frac{1}{M_1^2} \frac{1}{M_2^2} \exp(B_{dd}t) F_{dd}.$$

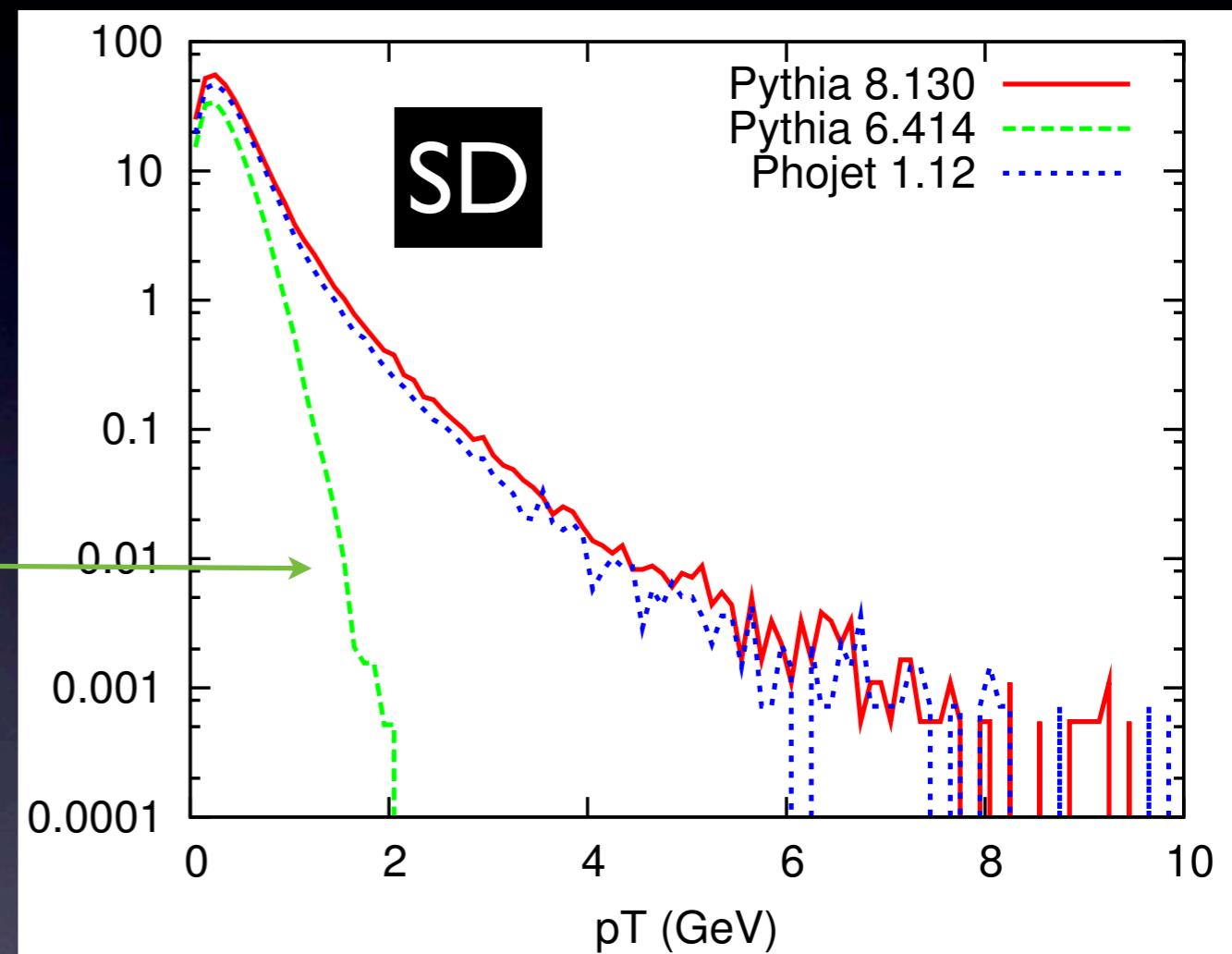
Spectra:

$2 m_{pi} < M_D < 1 \text{ GeV}$: 2-body decay

$M_D > 1 \text{ GeV}$: string fragmentation

Partonic Substructure in Pomeron:

Only in POMPYT addon (P. Bruni, A. Edin, G. Ingelman) ► high- p_T “jetty” diffraction absent



Very soft spectra without POMPYT

Status: Supported, but not actively developed

PYTHIA 8

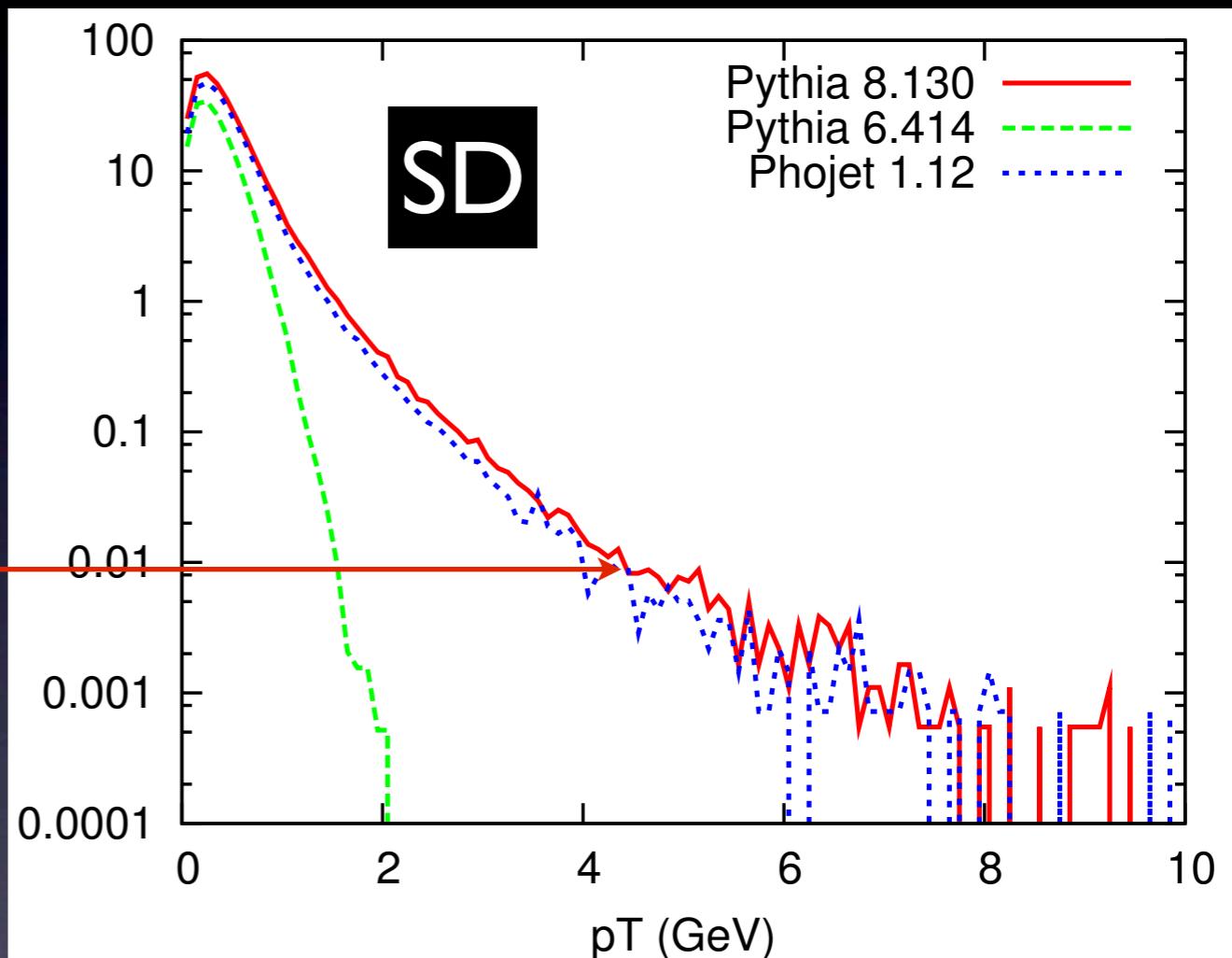
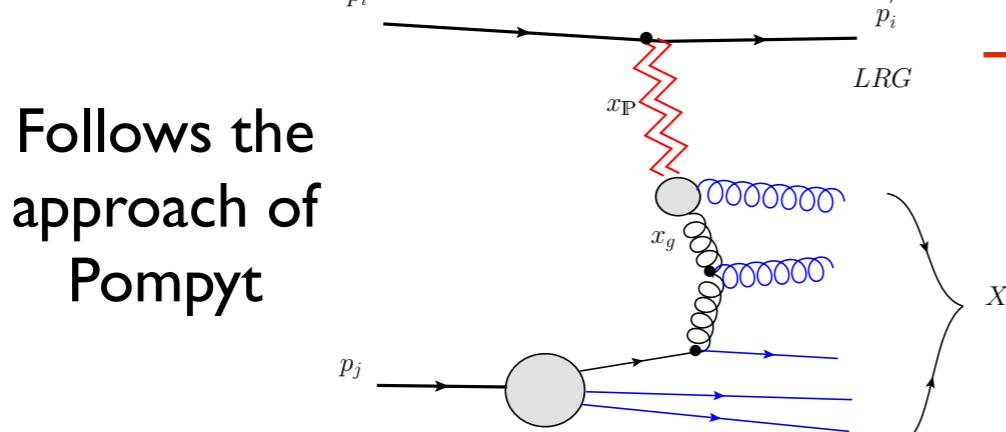
S. Navin (MCnet) + T. Sjöstrand

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Partonic Substructure in Pomeron:



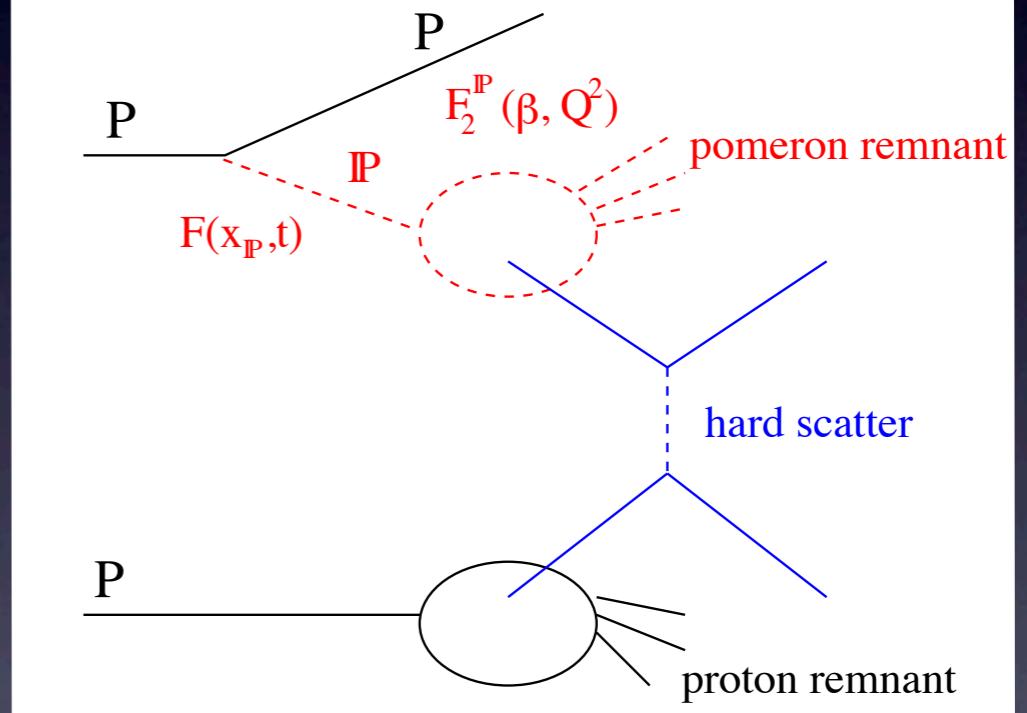
- ▶ $M_X \leq 10 \text{ GeV}$: original longitudinal string description used
- ▶ $M_X > 10 \text{ GeV}$: new perturbative description used

Status: Supported and actively developed

POMWIG & POMPYT

- Add-ons to F77 HERWIG and PYTHIA to include Pomeron structure
- POMWIG with DPEMC also includes central, e.g., $\text{P}^{\text{P}} \rightarrow \text{H}$

POMPYT: <http://www3.tsl.uu.se/hep/MC/pompyt/>
POMWIG: B. Cox, J. Forshaw, CPC144(2002)104
DPEMC: M. Boonekamp, T. Kucs CPC167(2005)217

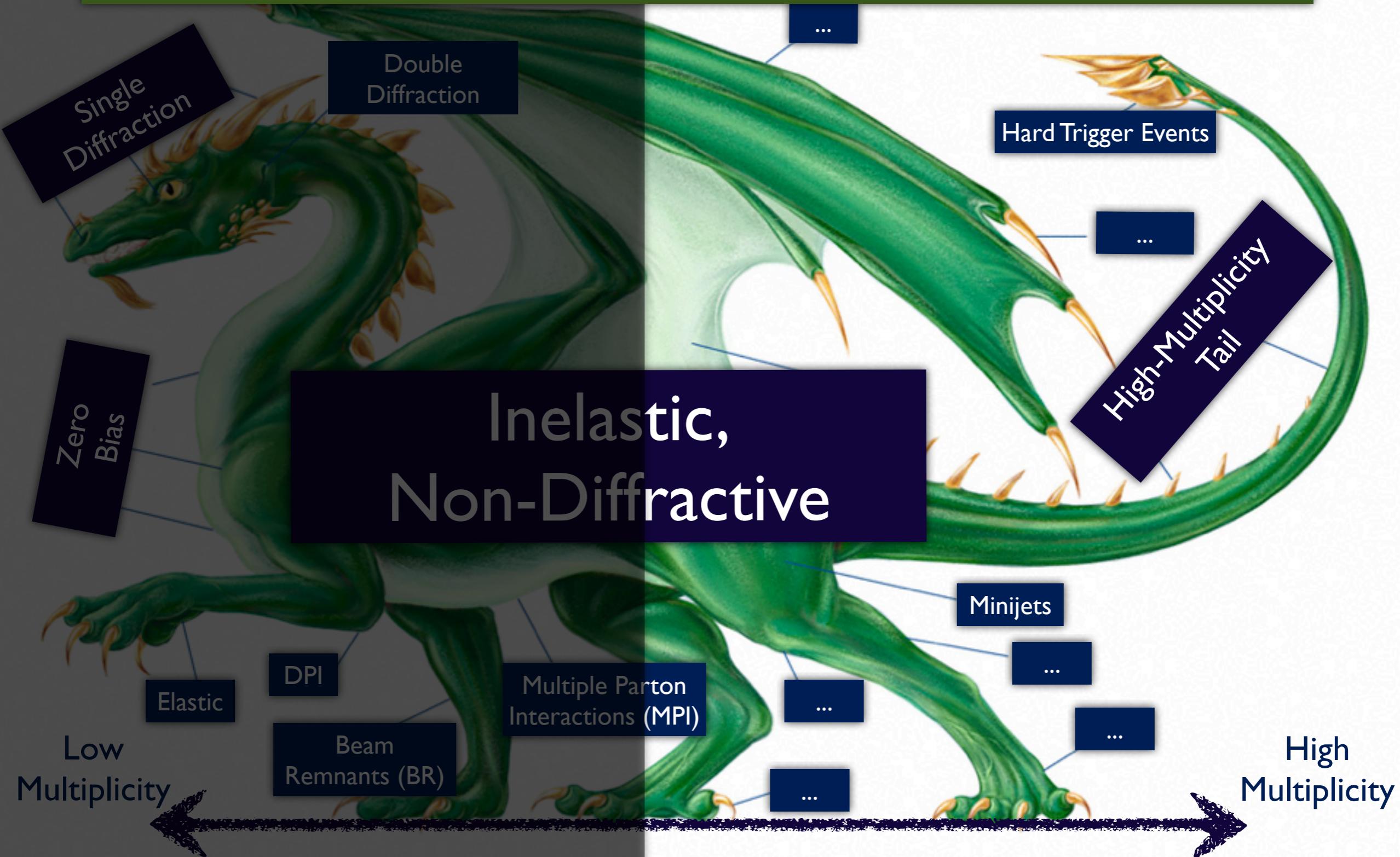


POMWIG Status: Stable, migrating to HERWIG++

Current Status

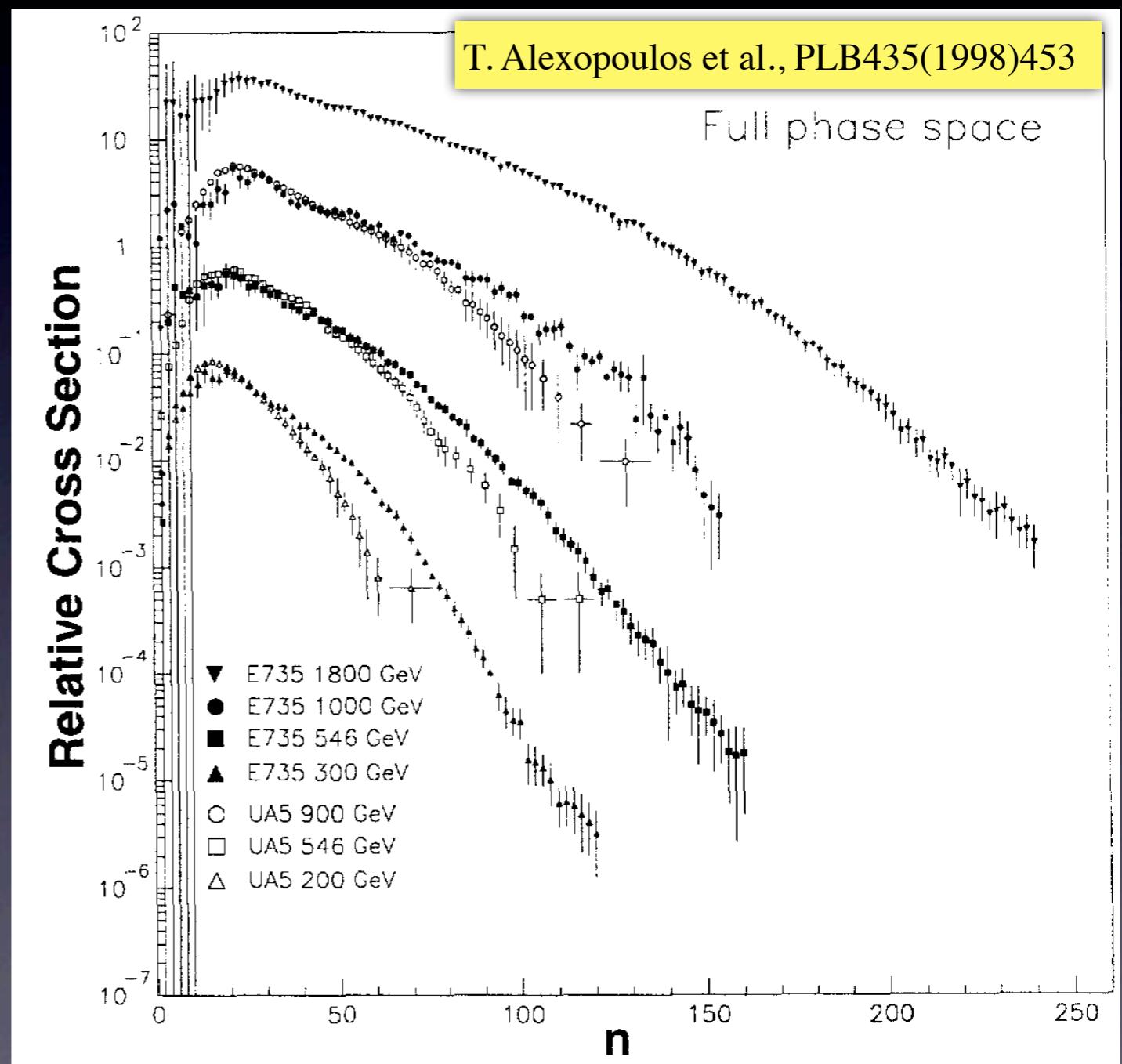
- PYTHIA 6 Obsolete
- POMPYT, POMWIG Stable
- PHOJET (& Relatives) Resurrected?
- PYTHIA 8 Active
- HERWIG++ R&D
- SHERPA (KMR: one to watch) R&D
- EPOS, RAPGAP, ... ?

Issues at High Multiplicity



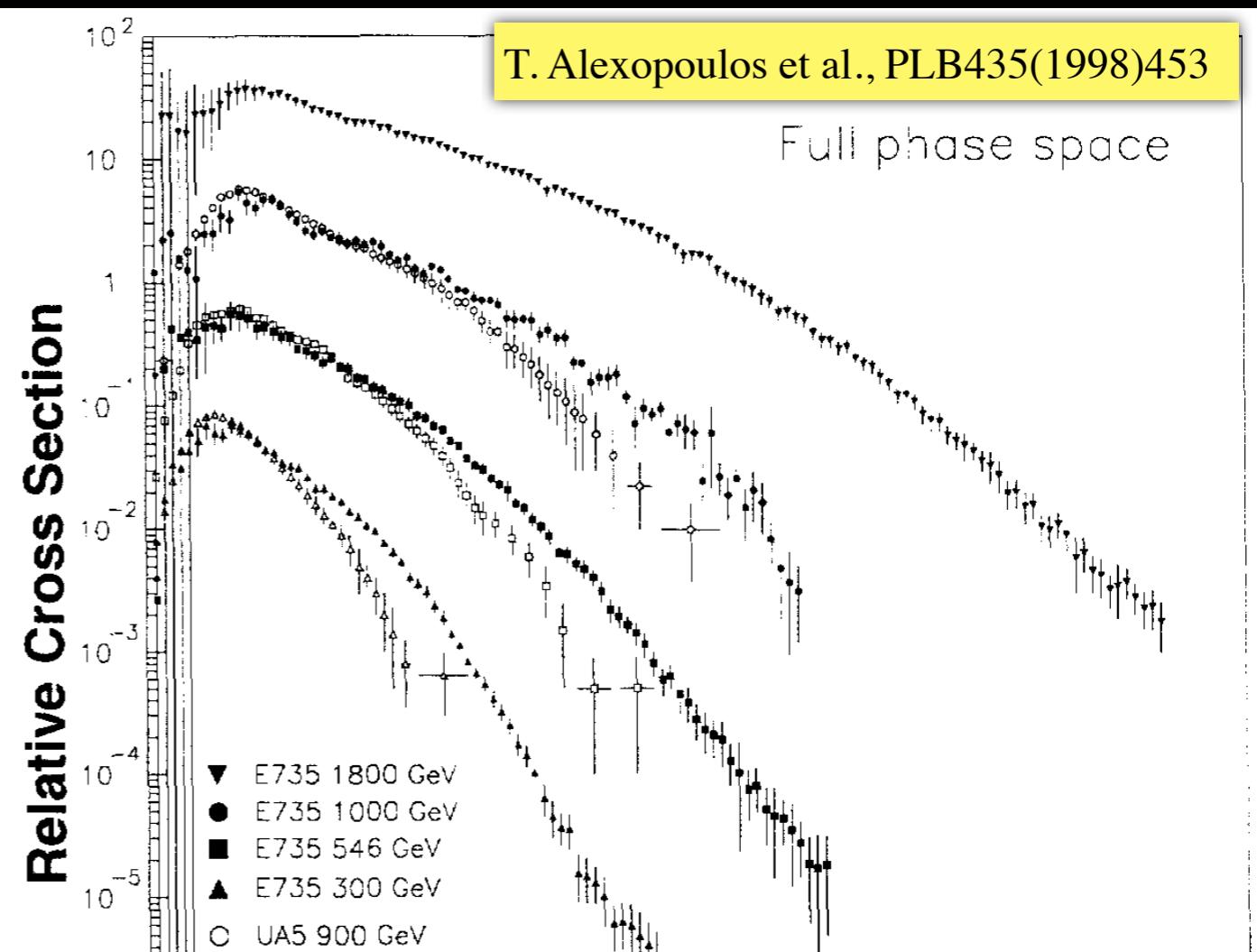
High Multiplicities: An Unresolved Question

- UA5 at 200, 546, and 900 GeV
- E735 at 300, 546, 1000, and 1800 GeV
- Mutually Inconsistent over Entire Range



High Multiplicities: An Unresolved Question

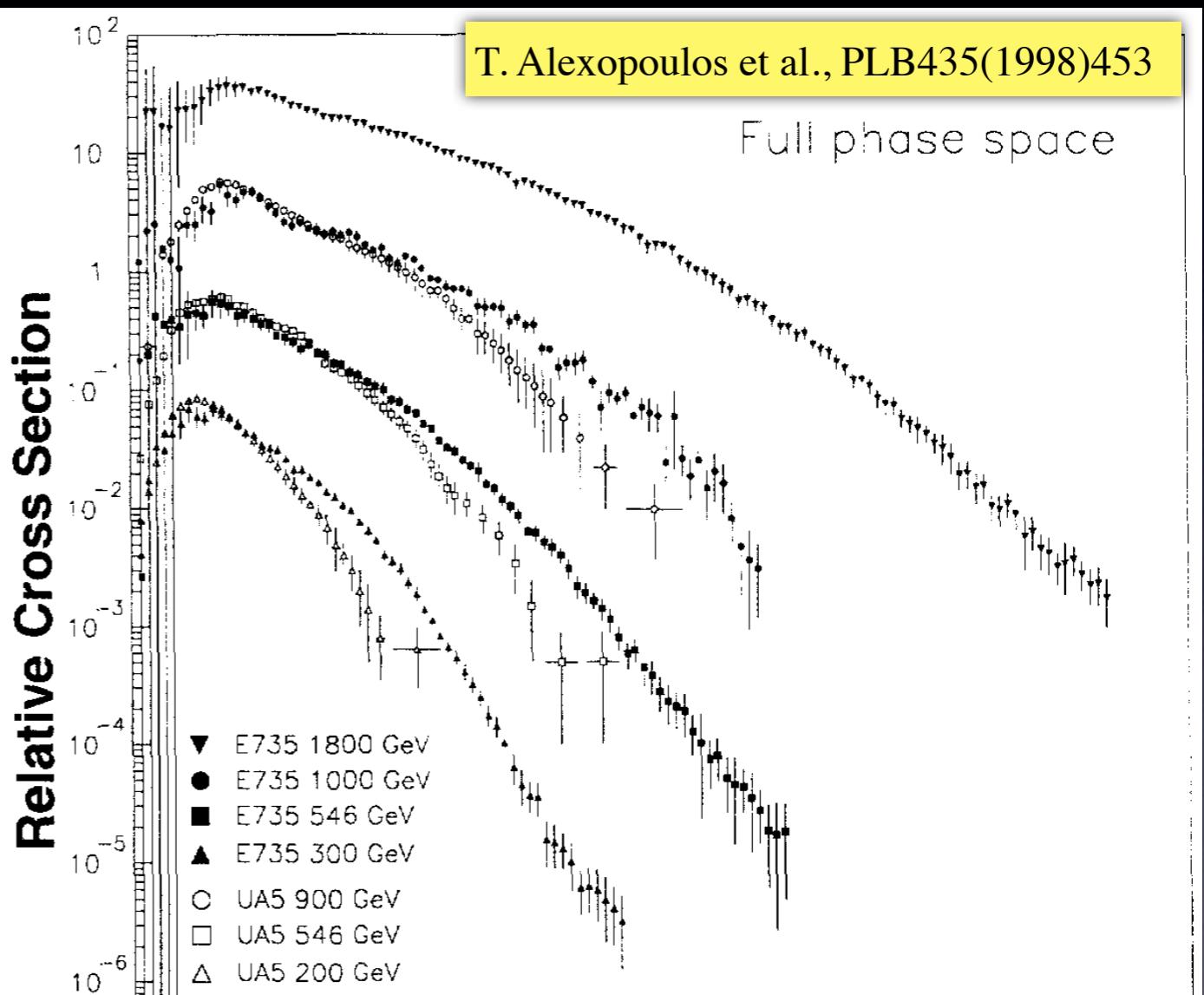
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Without even knowing how many tracks to tune to, how could we hope to constrain non-perturbative models (i.e., Monte Carlos) ?

High Multiplicities: An Unresolved Question

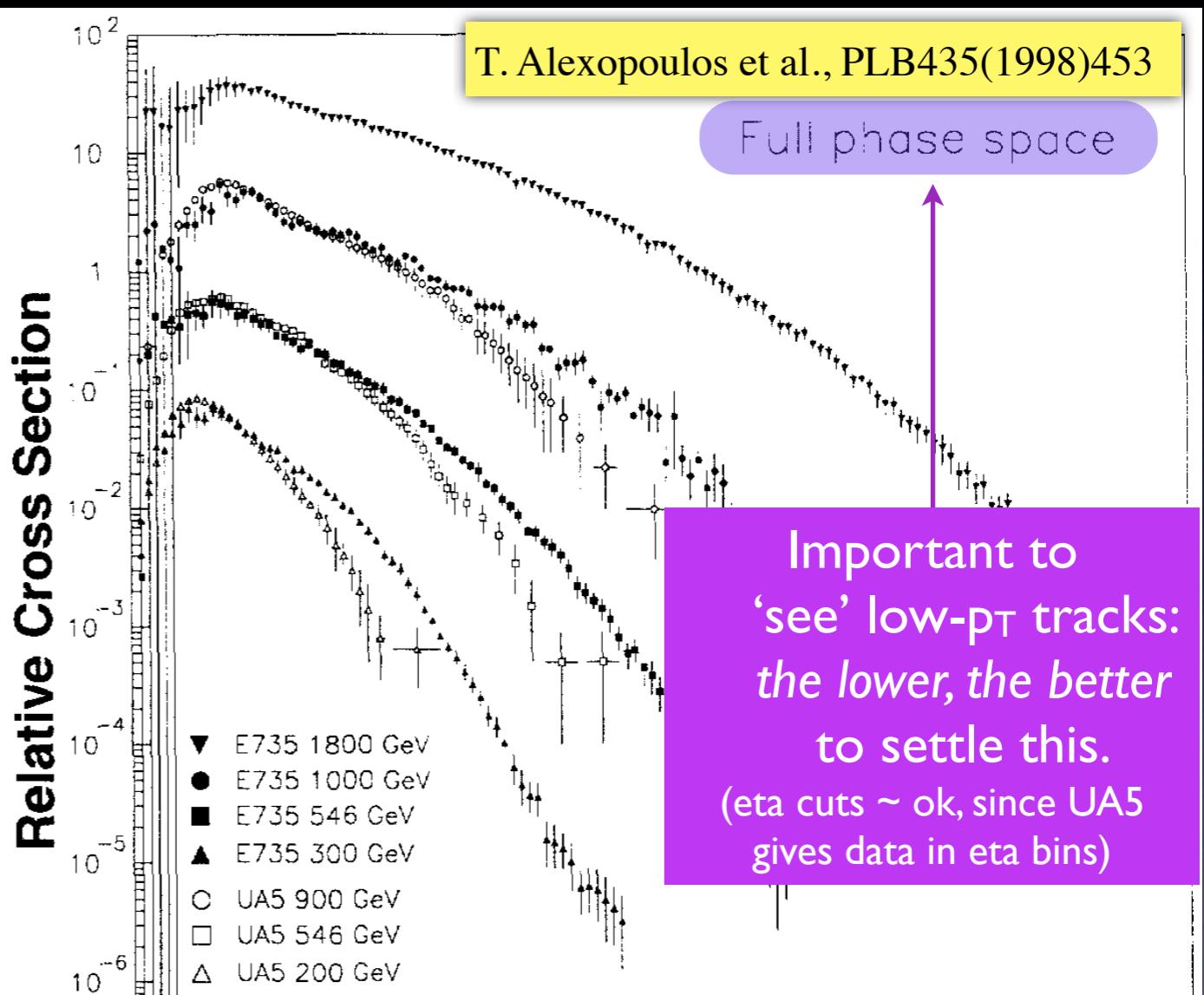
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Again: LHC Measurements at 900 and 2360 GeV are *the only way* to settle this question once and for all

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Fragmentation

- Normal MC Tuning Procedure:
 - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)

Fragmentation

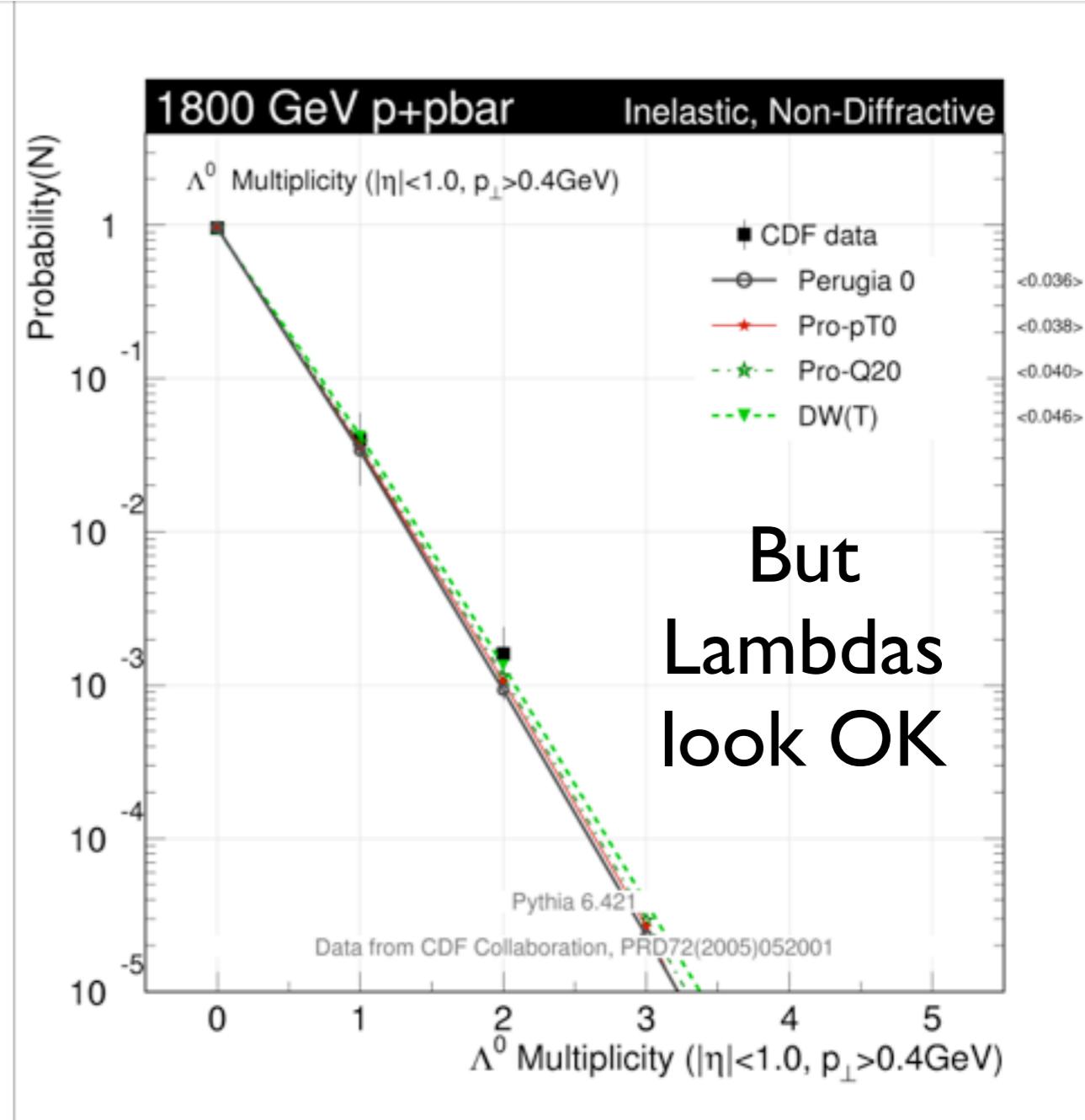
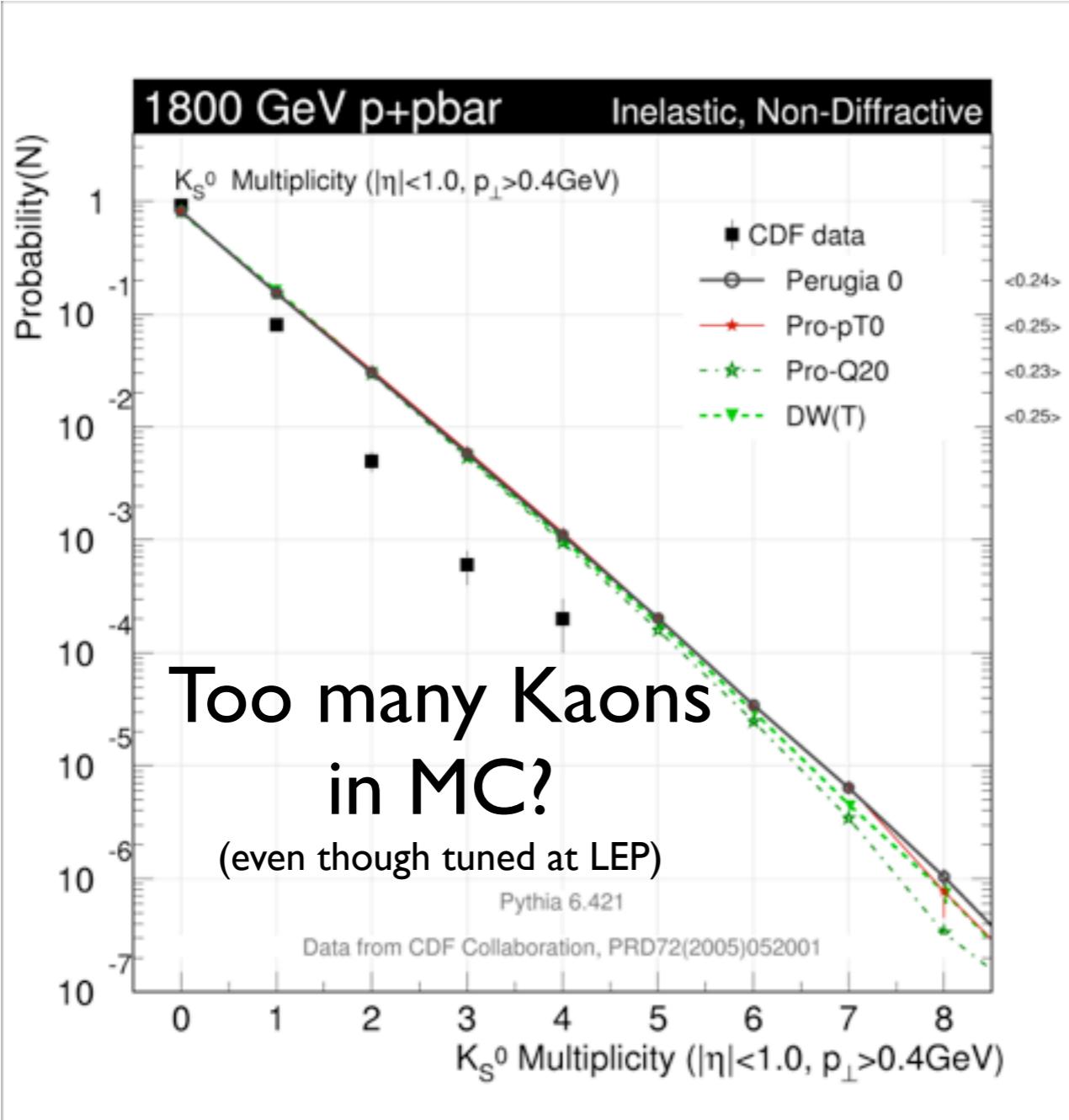
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- Check fragmentation *in situ* at hadron colliders
 - N and p_T spectra (and x spectra normalized to ‘jet’/minijet energy?)
Identified particles highly important to dissect fragmentation

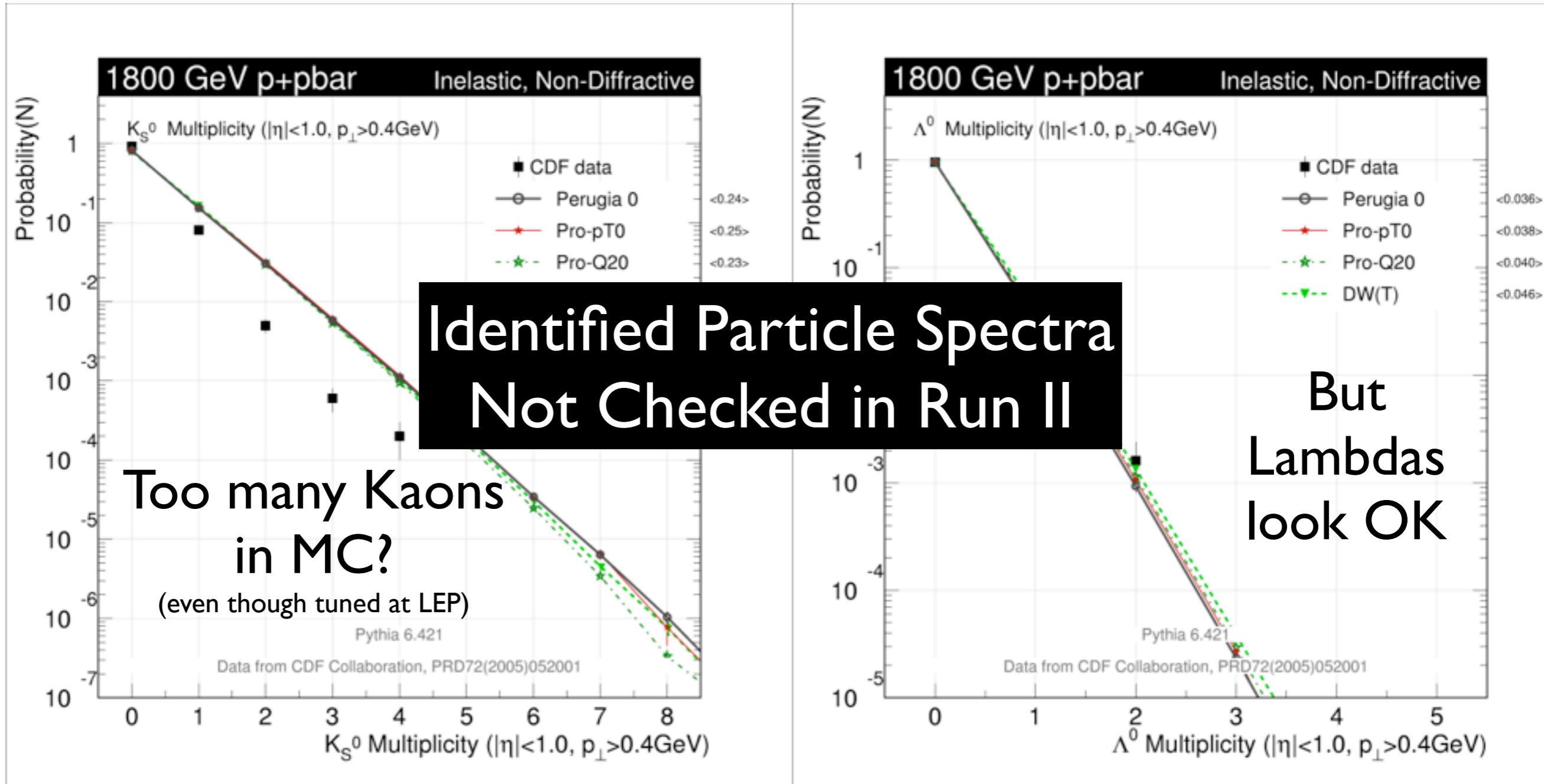
The Kaon Problem



<http://home.fnal.gov/~skands/leshouches-plots>

PS, fermilab-conf-07-706-t, in arXiv:0803.0678 [hep-ph]

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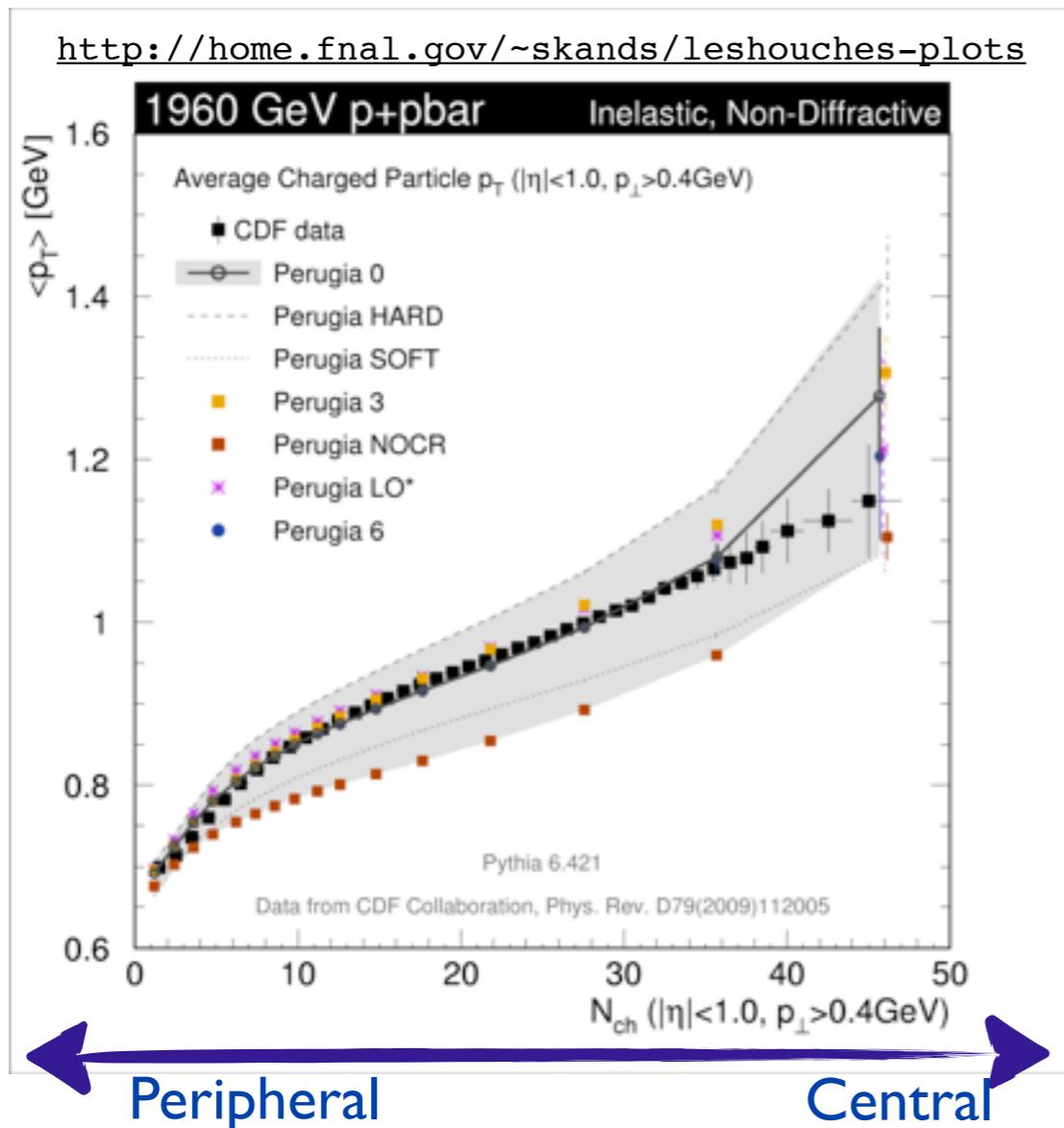
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- Check fragmentation *in situ* at hadron colliders
 - N and p_T spectra (and x spectra normalized to ‘jet’/minijet energy?)
Identified particles highly important to dissect fragmentation
 - (How) do the spectra change with (pseudo-)rapidity? (different dominating production/fragmentation mechanisms as fct of rapidity? E.g., compare LHCb with central?)
 - How do they change with event activity? (cf. heavy-ion ~ central vs peripheral collisions)

Change with Event Activity

- One (important) example: $\langle p_T \rangle(N_{ch})$



The p_T spectrum becomes harder as we increase N_{ch} .

Important tuning reference (highly non-trivial to describe correctly)

Fragmentation

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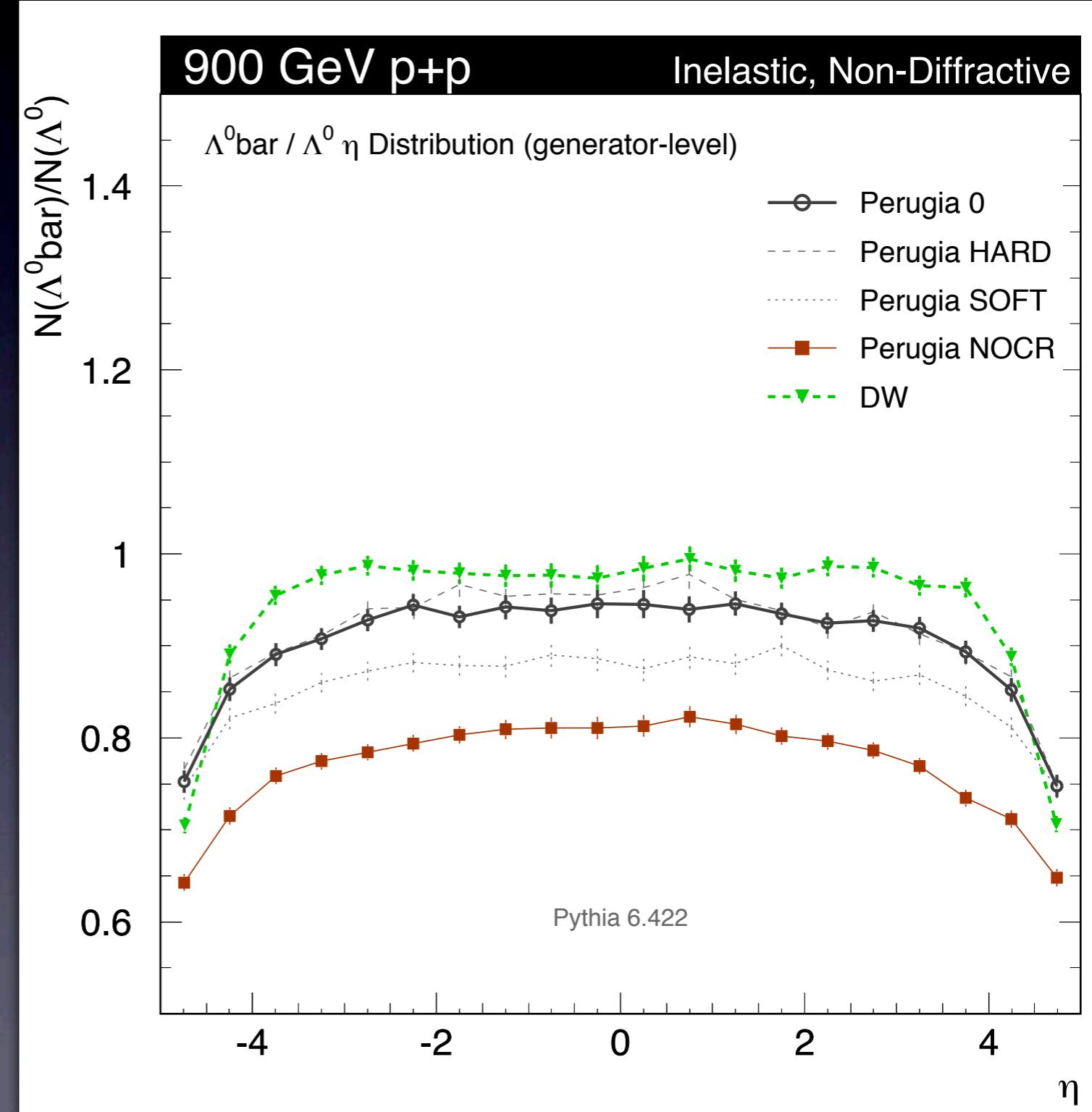
- Check extrapolation to forward region
 - Subir's synergy with Cosmic Ray Fragmentation
 - ‘New’ Physics: collective effects, multiple scatterings, low- x evolution, BFKL, ..., but central region remains important testing ground

(Additional Observables)

- **Particle-Particle Correlations** probe fragmentation beyond single-particle level. E.g.,:
 - A baryon here, where's the closest antibaryon?
 - + Is the Baryon number of the beam carried into the detector?
 - A Kaon here, where's the closest strange particle?
 - + Multi-Strange particles. Over how big a distance is the strangeness ‘neutralized’?
 - Charge correlations. Special case: is the charge of the beam carried into the detector?

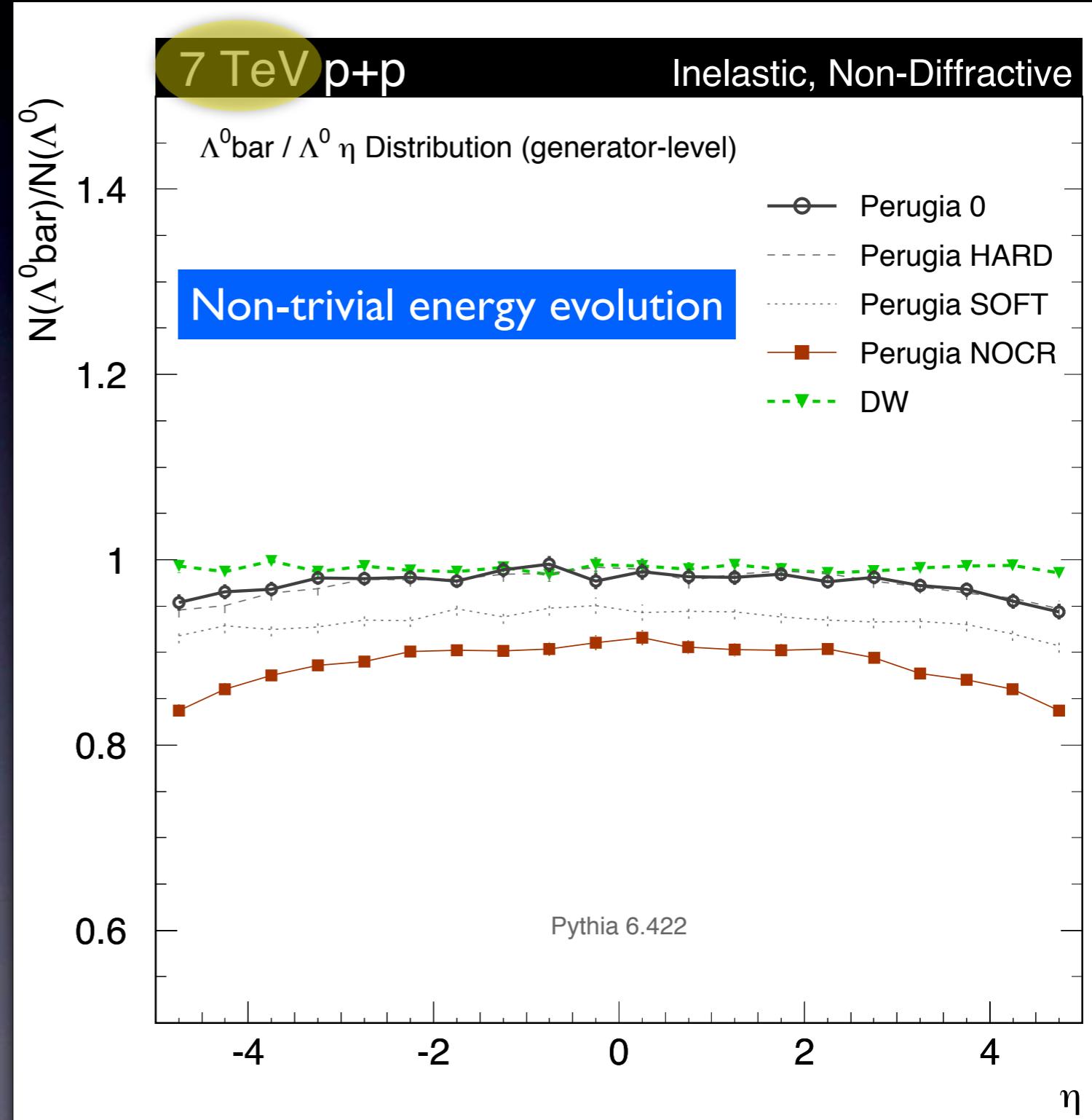
Baryon Transport

- Models disagree wildly.
- Don't listen to them
- (Still, can be used to gauge possible size of effect)



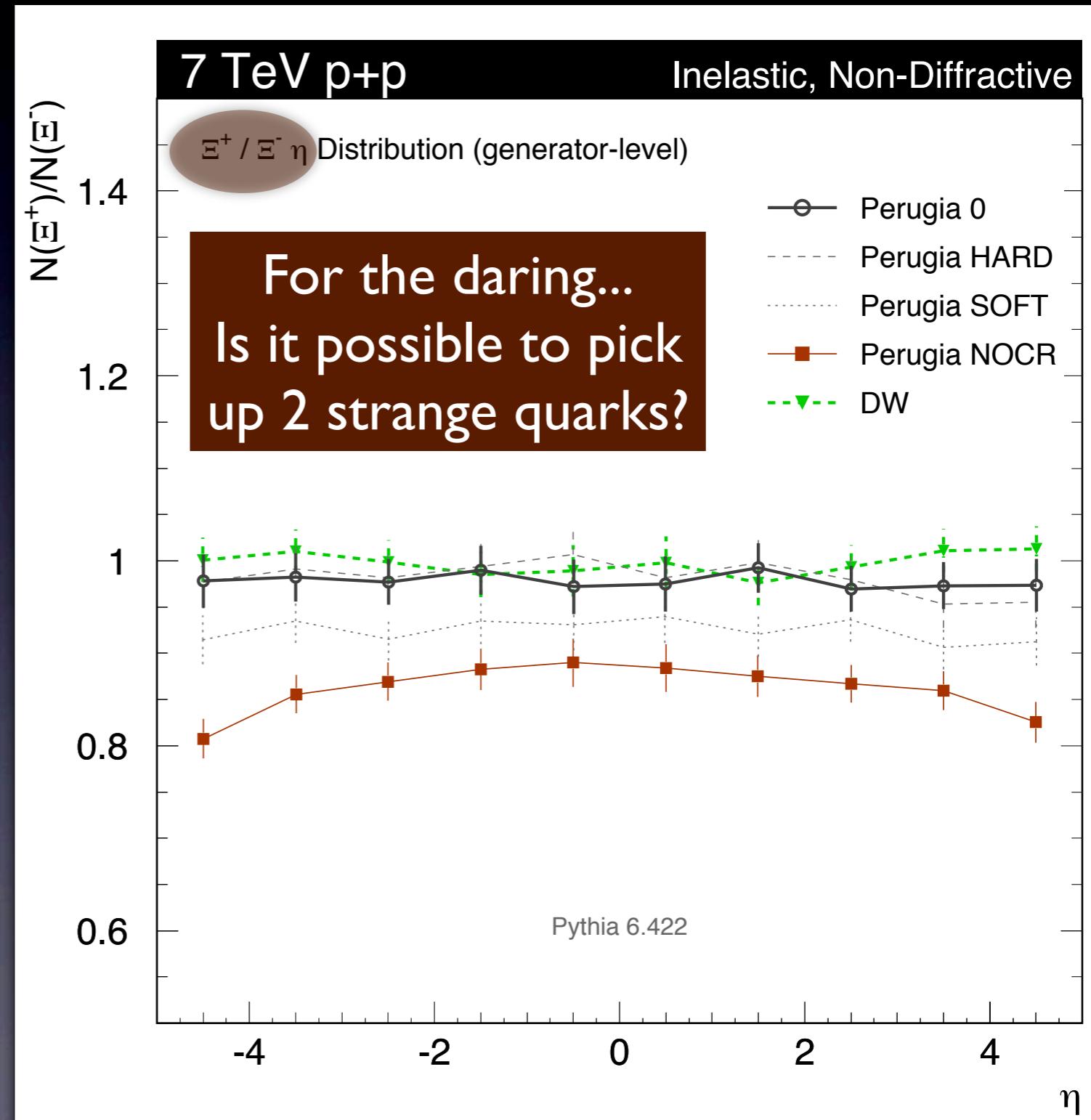
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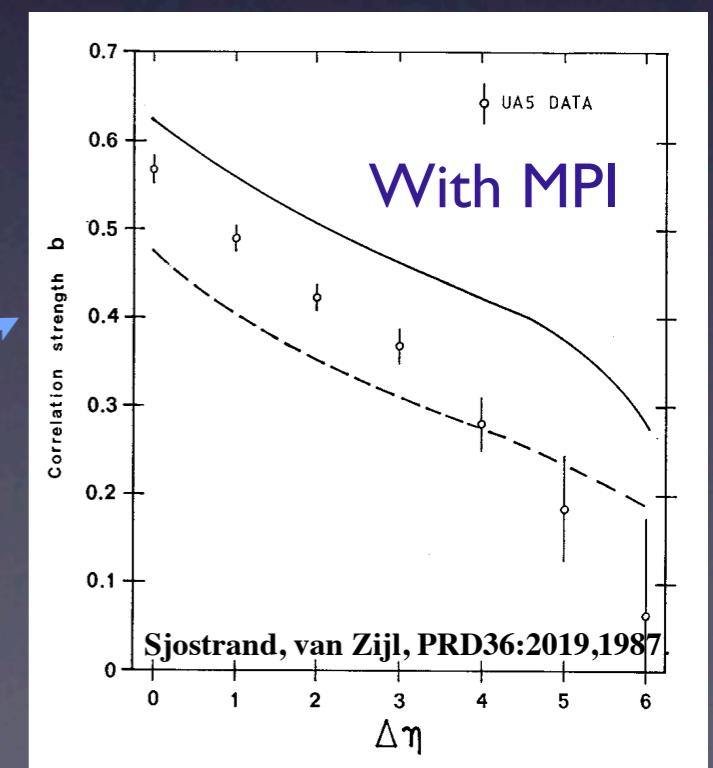
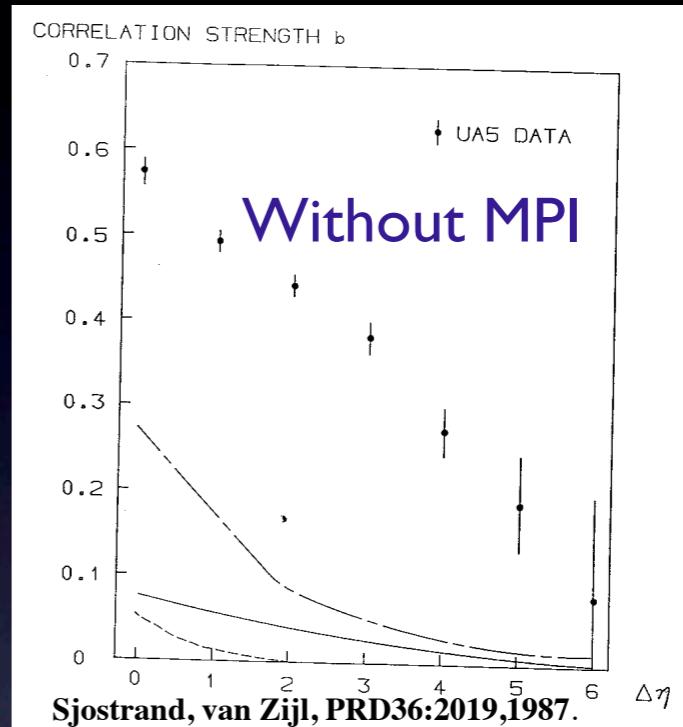


Radiation vs MPI

- What is producing the tracks?
 - Is it **Radiation**? (tends to produce partons close in phase space)
 - Or is it **MPI**? (partons going out in opposite directions)
 - Or is it soft production between the **remnants**?

Radiation vs MPI

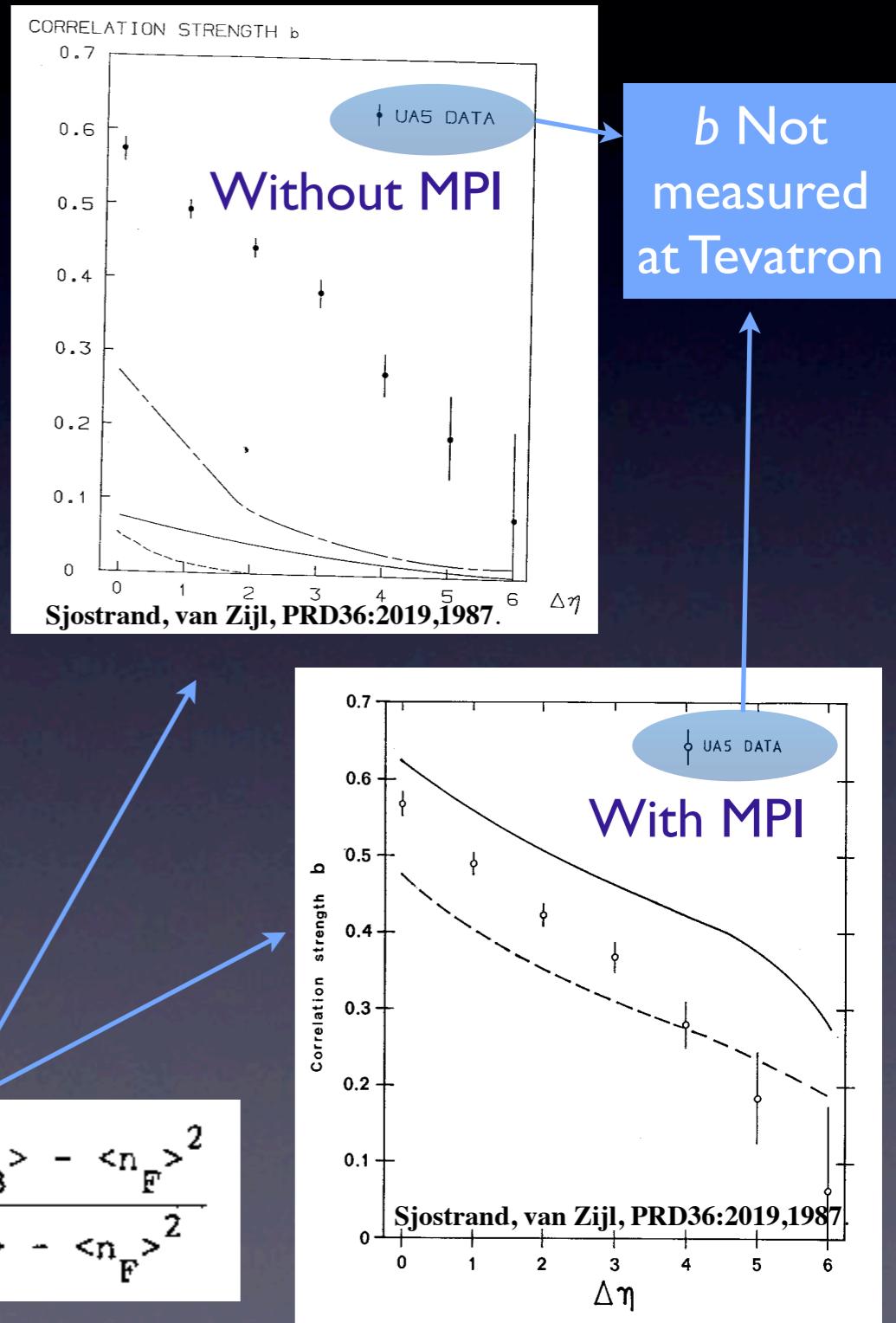
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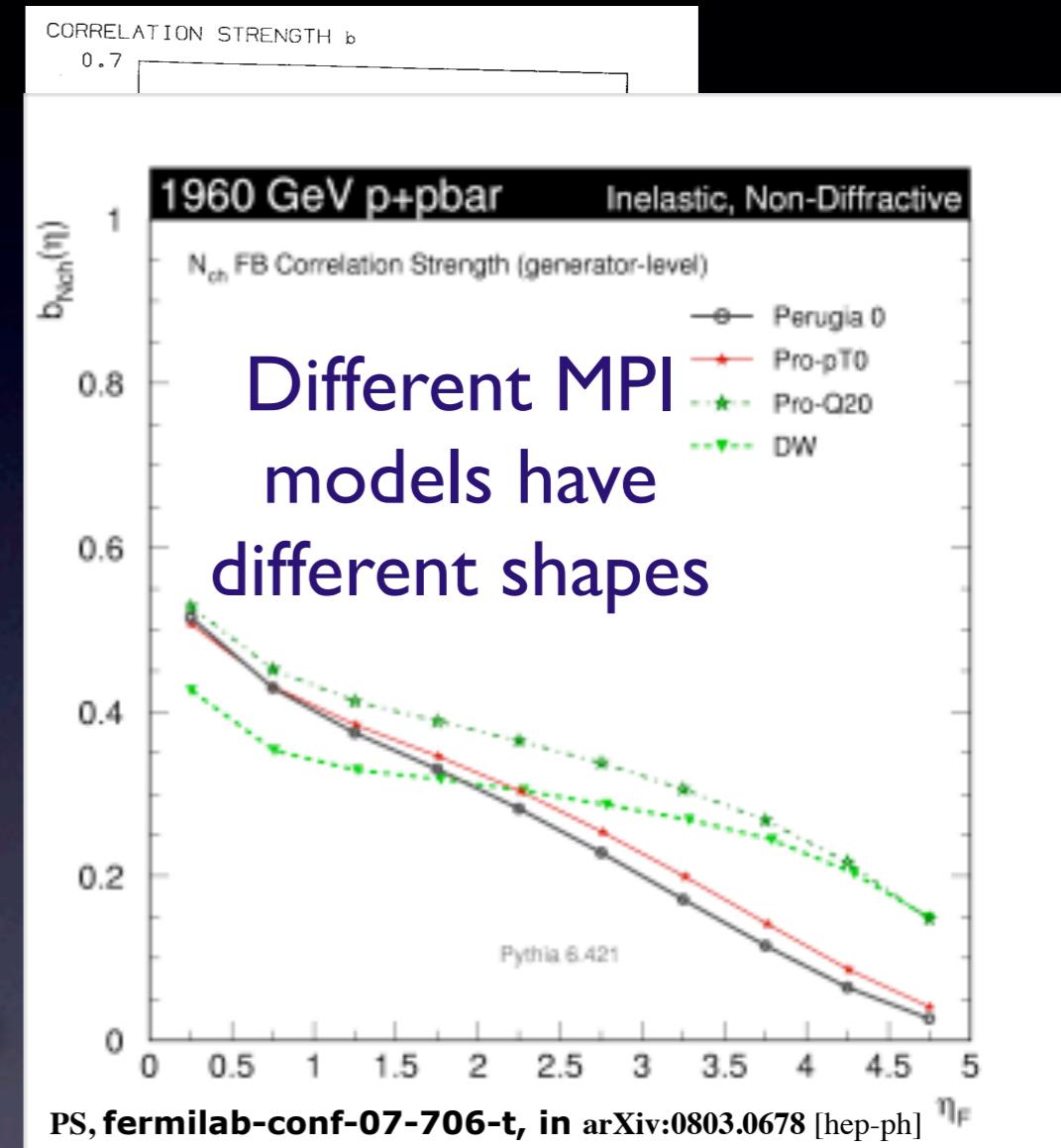
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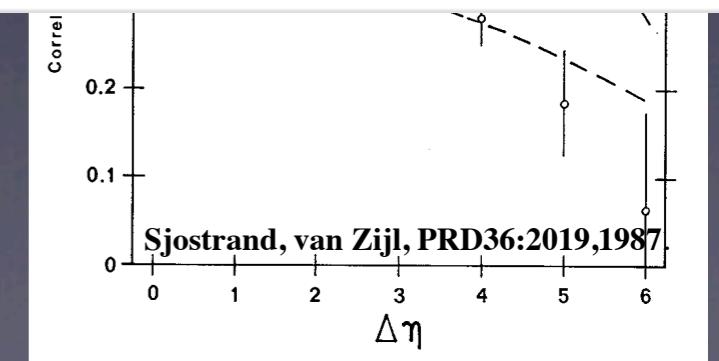
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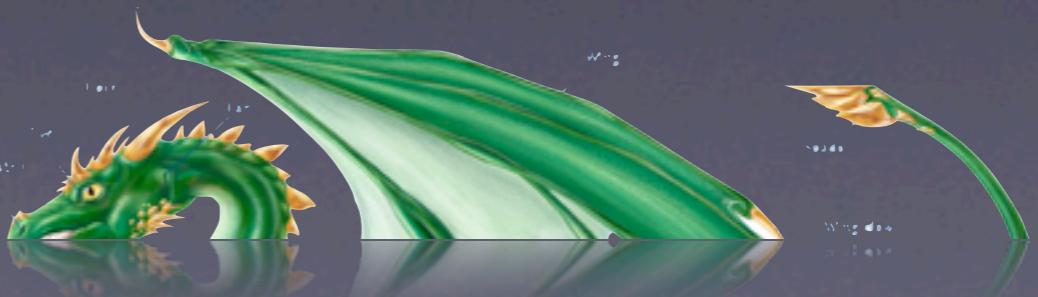


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Summary

- The Low-Energy LHC runs offer a unique possibility to settle important business
- These are questions faced by every person (within or outside experiments) trying to constrain ('tune') physics models
- In a broader context, they concern our knowledge of nature



A Systematic Dissection

Perturbative Dynamics :
Infrared **safe**
observables “pQCD”

Single-Jet Spectra
Jet-Jet distributions
IR safe Energy Flow variables

Non-perturbative dynamics :
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IR-sensitive vs IR-safe observables
(e.g., $\langle N_{ch} \rangle$ vs pT_{jet})

Single-Particle Spectra
Particle-Particle distributions
Quantum Number Flow variables

